Tail Biting Outbreak in Pigs

Prevalence, Early Detection and Targeted Intervention

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TAIL BITING OUTBREAK IN PIGS

- PREVALENCE, EARLY DETECTION AND TARGETED INTERVENTION

PHD THESIS 2018

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Contents

Preface and acknowledgements

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Summary

Tail biting in pigs is one of the major welfare challenges in modern pig production due to the behaviour's unpredictability and quick spread within a group of pigs. Even though routine tail docking is banned, most pigs reared within the EU are tail docked to reduce the risk of tail injuries. Tail docking is, however, a symptom-based treatment and does not remove the underlying cause triggering the abnormal tail biting behaviour. Producing pigs with intact tails in the current production systems without changes in management routines and production principles is expected to lead to a dramatic increase in tail damaged pigs.

Overall this PhD-project aimed to reduce the need for tail docking. This was achieved by investigating the consequences of not tail docking pigs in current production systems, by examining if behavioural changes occur prior to a tail biting outbreak, and whether providing enrichment just when the tail biting has started could reduce the prevalence of tail biting outbreaks.

To address these questions, four experiments were conducted in two commercial Danish piggeries. In the first study including 962 tail docked pigs (48 pens) and 960 undocked pigs (47 pens) at an expected low-risk tail biting piggery, the tail damage prevalence was recorded. Even though it was an expected low-risk tail biting piggery, 23 % of the undocked pigs distributed in 68 % of the pens received a tail injury, whereas none of the tail docked pigs got a tail injury. Despite this high on-farm prevalence, only 2 % of the undocked pigs received a tail lesion remark at the abattoir's meat inspection. To evaluate the consequences of not tail docking on animal welfare, tails should be scored on the farm, as abattoir meat inspection recordings underestimate the prevalence of tail damaged pigs.

In the second experiment including 2,301 undocked weaner pigs distributed in 74 pens (31 pigs per pen), it was investigated if changes in behaviour recorded at pen level occur prior to a tail biting outbreak. A tail biting outbreak was defined as four pigs with a tail wound irrespective of wound freshness. Tails were scored three times weekly prior to an outbreak. Results from video scan sampling observations showed almost a doubling in percentage of hanging tails in pens close to a tail biting outbreak (33 %) when compared to pens at least seven days away from an outbreak (17 %). This increase in hanging tails was also identified by direct recordings of tail posture from outside the pen. Additionally, an increase in the percentage of hanging tails was correlated with an increase in tail damaged pigs the following day. In contrast, no difference in activity, pigs at the feeder, exploratory behaviour, pen mate directed behaviour or tail directed behaviour was identified between upcoming tail biting pens and control pens.

The effect of early intervention on the prevalence of tail biting outbreaks was investigated in the third study including 1,804 undocked weaner pigs distributed in 60 pens (30 pigs per pen). The early intervention treatment was provided, when the first tail damaged pig or a tucked tail was observed from outside the pen. The early intervention consisted of either: no intervention (control), a small amount of straw, haylage in a spherical cage or a hanging rope with a sweet licking block. Providing pens with straw or haylage compared to nothing (control) when the first tail damaged pig was observed reduced the prevalence of tail biting outbreaks. The prevalence of tail biting outbreak did not differ between control pens and pens provided with rope. However, this was a small-scale study, and the results should, therefore, be interpreted with caution.

The effect of providing a small amount of straw, rope or a Bite-Rite (a plastic enrichment device with four protruding chew sticks, Ikadan Systems, Denmark) on tail damage was examined in pens with a tail biting outbreak in study IV. A small amount of straw prevented an escalation in tail injuries more efficiently than a Bite-Rite, whereas no difference was observed between supplying a hanging rope and straw or Bite-Rite. However, in pens provided with straw the tail biting continued in approximately one in four pens. This suggests that there is a need for additional studies investigating the effect of more efficient intervention strategies on tail biting in pens with a tail biting outbreak.

In conclusion, results demonstrated that rearing undocked pigs at an expected low-risk tail biting commercial piggery resulted in tail damage on approximately one in four of the pigs distributed in two-thirds of the pens. Additionally, it was demonstrated that the welfare impact of not tail docking should be established based on tail damage prevalence on farm and not on abattoir meat inspection prevalence. Results demonstrated that an increase in the proportion of pigs with hanging tails could be a promising tool to identify the tail biting in the early stages before causing severe outbreaks, and that providing even a fairly small amount of extra enrichment material when the first injured tail was observed reduced tail biting outbreaks.

Beside constant focus on minimising risk factors, trained stockperson taking care of undocked pigs can reduce tail damaged pigs markedly by observing and responding to hanging tails with minor injuries during the daily management routines.

To get a better understanding of tail biting, future research should examine how different risk factors – both internally motivated and externally motivated – influence the tail directed behaviour and not only the incidences of tail damage. Perhaps to reduce tail biting, certain risk factors should be in focus in the weaning period, whereas other risk factors are important to eliminate in the finisher period.

Sammendrag

Halebid er en af de helt store velfærdsudfordringer i svineproduktionen pga. adfærdens uforudsigelighed og hurtige eskalering. For at reducere risikoen for halebid halekuperes størstedelen af grise produceret i EU, selvom det ikke er tilladt rutinemæssigt. Problemet med halekupering som forebyggende tiltag er dog, at det er symptombehandling, da halekupering ikke fjerner de stressfaktorer, som udløser halebidsadfærden. Omvendt, hvis konventionelle grise ikke halekuperes, så vil det medføre en stor stigning i antallet af halebidte grise, hvis ikke managementrutiner og opstaldningsforhold ændres.

Formålet med dette Ph.d.-projekt var at reducere behovet for halekupering ved at undersøge konsekvenserne af ophør af halekupering i en besætning med lav forekomst af halebid blandt de halekuperede grise. Ligeledes havde projektet til formål at undersøge om adfærden ændres i stier med et kommende halebidsudbrud samt effekten af tildeling af ekstra beskæftigelsesmaterialer i stier hvor halebidningen lige er startet.

I projektforløbet blev der gennemført fire undersøgelser i to danske konventionelle besætninger. I den første undersøgelse blev frekvensen af halebidte grise sammenlignet mellem halekuperede og ikke-halekuperede grise. I undersøgelsen indgik 962 halekuperede grise (48 stier) og 960 ikke-halekuperede grise (47 stier) i en besætning med lav forekomst af halebid blandt de halekuperede grise. Resultatet viste, at 23 pct. af de ikke-halekuperede grise fordelt i 68 pct. af stierne fik en haleskade. Ingen af de halekuperede grise fik en haleskade. På slagteriet fik 2 pct. af de ikke-halekuperede grise en bemærkning for halebid. På grund af den lave forekomst af haleskader på slagteriet sammenlignet med i besætningen, så bør konsekvenserne af ophør af halekupering på dyrevelfærden vurderes på baggrund af forekomsten i besætningen.

I den anden undersøgelse med 2.301 smågrise med hele haler fordelt i 74 stier (31 grise per sti), blev det undersøgt, om adfærdsændringer kan identificeres forud for et halebidsudbrud. Der var halebidsudbrud i en sti, når fire grise havde en haleskade uanset sårets friskhed. Indtil der opstod et halebidsudbrud blev forekomsten af haleskader registreret tre gange om ugen. Videoobservationer viste, at dagen før et halebidsudbrud var der en fordobling i andelen af hængende haler (33 pct.) i stier tæt på et udbrud sammenlignet med kontrolstier (17 pct.), som var mindst syv dage fra et halebidsudbrud. Denne stigning i andelen af hængende haler op til et halebidsudbrud blev også fundet ved direkte at observere grisenes halepositur fra gangen. Ydermere viste undersøgelsen, at andelen af hængende haler dagen før et udbrud var positivt korreleret med antallet af halebidte grise på

udbrudsdagen. I undersøgelsen var der ikke forskel mellem kommende halebidsstier og kontrolstier på aktivitetsniveau, antal grise ved foderautomaten, eksplorativ adfærd, stifællerettet adfærd eller halerettet adfærd.

Effekten af en tidlig intervention på forekomsten af halebidsudbrud blev undersøgt i den tredje undersøgelse. Undersøgelsen omfattede 1.804 smågrise med hele haler fordelt i 60 stier. Den tidlige intervention bestod af enten en lille mængde halm, wrap i en metalkugle eller et hængende reb. Materialet blev tildelt, når den første gris fra gangen blev observeret med en haleskade. I undersøgelsen indgik også en kontrolgruppe uden tildeling af ekstra berigelsesmaterialer, når den første halebidte gris blev observeret. Hver gruppe med en tidlig intervention blev sammenholdt med kontrolgruppen. Resultatet fra denne undersøgelse viste, at de første haleskader kunne identificeres fra staldgangen og at tildeling af en lille mængde halm eller wrap reducerede risikoen for et decideret halebidsudbrud i forhold til i kontrolstier. Der blev ikke fundet en forskel i forekomsten af halebidsudbrud mellem reb- og kontrolstier. Dette var dog en mindre undersøgelse, hvorfor resultaterne bør tolkes med forsigtighed.

I det fjerde eksperiment, blev effekten af tildeling af en lille mængde halm, reb eller Bite-Rite (hængende materiale bestående af fire tyggepinde i plastik, Ikadan System A/S, Danmark) undersøgt på forekomsten af halebidte grise i stier med et halebidsudbrud. Resultaterne viste, at en lille mængde halm på gulvet var bedre til at standse halebidningen end en Bite-Rite, men der var ikke statistisk sikker forskel mellem reb og de to andre grupper. Dog fortsatte halebidningen i ca. 25 pct. af stierne med halm. Der er derfor behov for yderligere undersøgelser for at klarlægge, hvorvidt andre interventioner i stier med et halebidsudbrud mere effektivt kan standse halebidningen.

Samlet set viste projektets resultater, at produktion af ikke-halekuperede grise i en konventionel besætning med forventet lav risiko for halebid medførte, at en fjerdedel af grisene fordelt i to tredjedele af stierne fik en haleskade. Resultaterne viste endvidere, at konsekvensen på dyrenes velfærd ved ophør af halekupering bør vurderes ud fra forekomsten af halebidte grise i besætningen og ikke på baggrund af halebidsbemærkninger på slagteriet. Modsat viste resultaterne også, at dagligt tilsyn med halernes positur samt kontrol af hængende haler for haleskader er et lovende værktøj, der kan sikre, at halebidningen opdages tidligt, før der opstår et decideret halebidsudbrud. Ved tildeling af ekstra beskæftigelsesmaterialer på dette tidspunkt, så kan deciderede halebidsudbrud reduceres.

Udover konstant fokus på at minimere risikofaktorer for halebid, så kan staldpersonalet i forbindelse med de daglige tilsyn reducere forekomsten af halebid betragteligt ved at kigge efter små skader på hængende haler og reagere på dem ved at tildele ekstra beskæftigelsesmaterialer. Dette vil med stor sandsynlighed reducere forekomsten af og ikke mindst alvorligheden af de halebidsskader, der vil opstå, når grise ikke halekuperes.

For at få en bedre forståelse af halebidningens opståen, bør fremtidige studier undersøge, hvordan forskellige risikofaktorer, både dem der forårsaget af indre faktorer og dem, der skyldes eksterne faktorer, påvirker halebidsadfærden og ikke kun forekomsten af haleskader. Måske skal der i smågriseperioden være fokus på en type af risikofaktorer for at reducere halebidningen, mens der i slagtesvineperioden skal være fokus på andre faktorer.

1. Introduction

Tail biting in pigs is one of the most significant welfare problems in modern pig production, and it has been a challenge for many years (Van Putten, 1969; Sambraus, 1985; Schrøder-Petersen and Simonsen, 2001). Tail biting is considered an abnormal behaviour (EFSA, 2007; Sutherland and Tucker, 2011) only reported in domesticated pigs – both in the organic, free range and conventional production (Alban et al., 2015; Kongsted and Sørensen, 2017). To reduce tail damage (Sutherland and Tucker, 2011), most pigs reared within the EU are tail docked (EFSA, 2007), despite a ban on routine tail docking (EC, 2016). However, using tail docking as a preventive measure against tail biting is problematic, because tail docking is a symptomatic treatment and it does not remove the initial stressors triggering the tail biting (EFSA, 2007).

In the literature, many risks factors have been linked with tail biting. The most frequent cited risks factors are: lack of enrichment, impaired climate, poor health, genetics and sub-optimal feeding (Schrøder-Petersen and Simonsen, 2001; D'Eath et al., 2014). However, even though many risks factors have been linked with tail biting, it is poorly understood what triggers the behaviour (Taylor et al., 2010). Taylor et al. (2010) proposed that the behaviour occurs due to boredom, frustration or internal health challenges, and is therefore an indication of stress in the biter. Boredom or frustration might occur amongst domesticated pigs if the housing environment is inappropriate and lacking proper environmental stimuli, as argued by Schrøder-Petersen and Simonsen (2001). The causal relation between 'internal health challenges' and tail biting is, however, not evident (D'Eath et al., 2014), but a recent small-scale study including 13 pigs from 13 pens with respiratory disease demonstrated that pigs with respiratory disease had a non-significant tendency to perform more tail biting than healthy pigs (Munsterhjelm et al., 2017).

Tail biting is difficult to predict as it occurs sporadically, and it can escalate within a short time causing actual outbreaks, as discussed by D'Eath et al. (2014). Being tail bitten is painful (EFSA, 2007), and if not stopped, the behaviour can cause partial or complete tail loss (Kritas and Morrison, 2004; Harley et al., 2012) with subsequent increased risk of infections in the tail region or abscesses in other parts of the body (Teixeira et al., 2016; Fertner et al., 2017).

It is likely not possible to eliminate all tail biting risk factors in conventional production systems, thus some tail biting will occur. It has been proposed that rearing pigs with undocked tails in standard conventional production systems will increase the number of tail damaged pigs from 3 % to 17 % (D'Eath et al., 2016) and increase the prevalence of severe tail lesions by 50 % (Valros and Heinonen, 2015). The consequences of producing pigs with undocked tails in current production systems have, however, not been verified in experimental studies. The first step in a transition to intact tails is therefore to establish the prevalence and severity of tail injuries among undocked pigs in current production systems.

Through the years a lot of research has been conducted on tail biting. Studies have mainly examined the risk factors associated with tail injuries and tail biting (reviewed by (Schrøder-Petersen and Simonsen, 2001; Taylor et al., 2010; D'Eath et al., 2014; EFSA, 2014; Brunberg et al., 2016)). However, beside reducing risk factors, it is also relevant to examine if pens with a future tail biting outbreak can be identified before an outbreak is ongoing. If pens with an upcoming tail biting outbreak can be identified earlier, this opens up the possibility to stop the behaviour in its early stages. A few previous studies reported behavioural changes in the days before the outbreak (Statham et al., 2009; Zonderland et al., 2009), but as concluded in Larsen et al. (2016), more research is needed to establish these potential behavioural indicators of a future tail biting outbreak.

If changes in behaviour can be used to identify pens with tail biting, then an intervention to stop the behaviour can be carried out earlier and thereby prevent severe outbreaks. However, very little research has been conducted within this area. Only one experimental study investigated how to prevent a further increase in tail damaged pigs during an ongoing tail biting outbreak (Zonderland et al., 2008). In the study, removing the biting pig or giving a small amount of straw (20 g/pig/day) reduced the prevalence of fresh wounds equally. More experimental studies are therefore needed to establish how different enrichment materials applicable under conventional conditions influence tail biting when tail damaged pigs are present.

Therefore, if more pigs are to be reared with intact tails without a dramatic increase in tail damaged pigs, there is, first of all a need to establish and understand the consequences of not tail docking pigs in the current production systems. Secondly, it should be investigated if tail biting outbreaks can be identified in the early stages, and thirdly, how efficiently different enrichment interventions affect the number of tail damaged pigs - both just when the first tail damaged pigs is observed and during a tail biting outbreak. This PhD thesis will deal with these three topics with the overall aim to reduce the need for tail docking.

1.1 Thesis outline

This thesis consists of a synopsis and four papers. The synopsis contains the overall introduction (This chapter – Chapter 1) followed by a chapter on background (Chapter 2) presenting and discussing the relevant scientific tail biting literature. Chapter 3 describes the data collection methods used to answer the hypotheses. Following this is Chapter 4 presenting the results. Chapter 5 discusses the data collection methods and results in relation to other studies. At the end of the chapter is a discussion of the project's practical implications. Finalising the synopsis is a concluding chapter (Chapter 6) relating the findings and implications in the studies with the aim. Following the conclusion is perspectives of the interpretation of results and the opportunities for future research. In the appendix following the synopsis are the four papers presenting and discussing the results from the studies in detail:

Paper I: **More tail lesions among undocked than tail docked pigs in a conventional herd**. 2017. Lahrmann H.P., Busch, M.E., D'Eath, R., Forkman, B., Hansen, C.F., Animal 11, 1825-1831.

Paper II: **Tail posture predicts tail biting outbreaks at pen level in weaner pigs.** 2018. Lahrmann, H.P., Hansen, C.F., D'Eath, R., Busch, M.E., Forkman, B., 2018. Applied Animal Behaviour Science 200, 29-35.

Paper III: **Early intervention with enrichment can prevent tail biting outbreaks in weaner pigs.** 2018. Lahrmann, H.P., Hansen, C.F., D'Eath, R.B., Busch, M.E., Nielsen, J.P., Forkman, B., Livestock Science 214, 272-277.

Paper IV: **Comparing straw, rope and Bite-Rite as treatments for tail biting outbreaks in weaner pigs.** Lahrmann, H.P., Hansen, C.F., D'Eath, R.B., Nielsen, J.P. and Forkman, B. In prep manuscript.

2. Background

Tail biting is an abnormal behaviour which has been seen in a number of species kept in captivity (e.g. calves (Millar and Kenward, 2015); mink (Mason, 1994; Hansen et al., 1998; Vinke et al., 2002); silver foxes (Braastad, 1987)), but is most known to occur in pigs (EFSA, 2007). In pigs, tail biting is a complex problem and is considered one of the most important welfare issues leading to 97 % of all pigs born in Europe being tail docked to reduce the risk of tail biting (EFSA, 2007).

Other forms of injurious behaviour share some of the common features with tail biting with the most well investigated being feather pecking in hens (Brunberg et al., 2016). Brunberg et al. (2016) argued that the common features could be due to the species' common omnivorous origin and suggested that both species for instance shows a high level of exploration.

In pigs, tail biting has been a challenge for many years, as discussed by Sambraus (1985). In 1966-1967 Van Putten (1969) investigated the effect of straw and climate on tail biting, and since then many studies have been carried out in the attempt to better understand and eliminate the tail biting problem (reviewed by Schrøder-Petersen and Simonsen (2001); D'Eath et al. (2014)). To understand the challenges with tail biting and identifying knowledge gaps, it is essential to review and discuss the current knowledge on; what tail biting is, why it arises, the consequences of the behaviour, how it might be prevented and if it occurs how it might be stopped. These topics are introduced and discussed in this chapter.

2.1 Defining tail directed behaviour and tail biting

In the scientific literature, tail directed behaviour is divided into the pre-injury stage (tail nosing/tail interest and tail-in mouth) and the injury stage (tail biting) (Schrøder-Petersen and Simonsen, 2001; Taylor et al., 2010). In the pre-injury stage, the term tail interest/nosing is used when a pig is nosing the tail of a pen mate without taking the tail in the mouth (Paoli et al., 2016). The term tail-in-mouth is used when the performing pig takes the tail in the mouth and manipulates it (Schrøder-Petersen et al., 2003) without a sudden reaction of the receiver (Zonderland et al., 2011b; Paoli et al., 2016). These pre-injury stages of the tail directed behaviour does not always lead to tail biting (Schrøder-Petersen et al., 2003; Paoli et al., 2016), but it has been suggested that increasing incidences of pre-injury tail manipulation increase the risk of tail damage (Taylor et al., 2010). The injury stage of the behaviour, termed tail biting, occurs when the chewing behaviour inflicts a visible lesion (scratch or wound), and/or the behaviour creates an immediate reaction (moving away, squealing of the receiver; (Zonderland et al., 2011b; Paoli et al., 2016)).

What causes the shift from pre-injury tail manipulation to damaging tail biting remains unsettled, but different theories have been proposed. It has been suggested that the taste of blood from the small wounds during the pre-injury manipulation (Fraser, 1987) or tail wagging due to pain (Van Putten, 1969) increase the tail interest, leading to an escalation in the biting behaviour.

In the following, as in Taylor et al. (2010), the term 'tail biting' refers to the behaviour leading to tail damage.

2.2 The etiology of tail biting

It is widely agreed that stressors in the environment trigger the injurious tail biting (Schrøder-Petersen and Simonsen, 2001; Taylor et al., 2010; Brunberg et al., 2016). Stressors are external stimuli triggering an adaptive mechanism in the animal as a response (stress response) to those stimuli (Morméde et al., 2007). Depending on the strength and duration of the stressor, the stress response can either be short-term or long-term (Morméde et al., 2007). As tail biting is a response to stressors in the environment, the behaviour itself indicates an underlying welfare problem (Schrøder-Petersen and Simonsen, 2001; Taylor et al., 2010; Brunberg et al., 2016).

The factor or factors triggering tail biting likely differs from piggery to piggery and perhaps even between pens, as both internal factors, such as genetics (Breuer et al., 2005), gender (Zonderland et al., 2010), health (Munsterhjelm et al., 2017) and external factors such as climate (Temple et al., 2012), enrichment access (reviewed by D'Eath et al. (2014)), feeding (McIntyre and Edwards, 2002; Meer et al., 2017) and stocking density (Larsen et al., 2017) influences the behaviour. The many risk factors affecting tail biting are probably also the reason why tail biting occurs in a wide variety of production systems including organic and free-range systems which is characterised by lower stocking density, access to an outdoor run, straw etc. (Alban et al., 2015; Kongsted and Sørensen, 2017). However, as discussed by Taylor et al. (2010) incidences of tail biting have not been reported among non-domesticated species.

Tail damage, as a result of tail biting mainly occurs in the grower and finisher period, where it has been observed in different age groups (Schrøder-Petersen and Simonsen, 2001; Ursinus et al., 2014a; Scollo et al., 2016). One study did also report tail wounds on 9.2 % of the pigs at weaning (Ursinus et al., 2014a) while another study observed no tail damaged pigs during the lactation period (Veit et al., 2016). It is not evident why tail biting predominantly occurs in the grower and finisher period and not later when pigs reach sexual maturity.

It is often one or a few pigs in a pen that perform the majority of the tail biting (Van de Weerd et al., 2005; Zonderland et al., 2011a; Zupan et al., 2012). This is likely due to differences in pigs' behavioural response in stressful situations (Bolhuis et al., 2004; Brunberg et al., 2016). Some pigs may be more likely to tail bite as a response to a stressor than others.

Taylor et al. (2010) suggested three different underlying motivations to explain why some pigs start tail biting. The 'two-stage' biting was suggested to be motivated by pigs' behavioural need to perform explorative behaviour (Taylor et al., 2010). A behavioural need can be defined as species-specific behaviour that the animal is highly motivated to perform and if the performance is prevented, the animal may experience frustration and reduced welfare (Jensen and Toates, 1993). Appropriate manipulative substrates must be present to fulfil pigs need to perform exploratory behaviour. If appropriate materials are missing, pigs may instead manipulate and gently chew on the tail of pen mates (pre-injury stage), and in time scratches and wounds can appear (injury stage). The second type of tail biting named 'sudden-forceful' was suggested to be motivated by frustration (Taylor et al., 2010). In this case, a pig suddenly chews hard on a pen mate's tail, instantly leading to a bleeding wound. Frustration was defined by Taylor et al. (2010) as the emotional state that pigs might experience when blocked from a resource they are highly motivated to access. As an example, Taylor et al (2010) described a potentially frustrating situation as, when a highly valued resource such as feed or an area to rest, can only be reached by a few pigs leading to enhanced competition. The third type of tail biting introduced by Taylor et al. (2010) is performed by the 'obsessive biter', which is a pig primarily occupied with chewing pen mates' tails. These pigs perhaps find the biting behaviour self-rewarding, and Taylor et al. (2010) suggested that some pigs become 'obsessive biters' due to poor health/growth or other internal 'challenges'. However, the underlying motivation triggering the 'obsessive biter' might be the same as for the 'two-stage' and 'sudden forceful' biting. It may be the individual coping mechanism of the animal (such as genetics, health or stage of development) that determines if it becomes an 'obsessive biter'. Differences in the coping mechanism may therefore determine whether a pig is more or less reluctant to continue tail biting once started.

Recently Valros (2018) suggested a fourth type of tail biting termed 'epidemic'. Valros (2018) suggested that 'epidemic' tail biting occurs as a reaction to a sudden and acute stressor, whereas the 'two-stage' biting might be a response to chronic stressors in the environment, such as high stocking density and permanent lack of suitable manipulable materials. The internal motivation for 'epidemic' tail biting, may however, be the same as for ‘sudden-forceful’ and ‘two-stage’ biting. The difference may be, that ‘epidemic’ tail biting is triggered by a more evident (to the human) environmental stressor (like feeding disturbances or a sudden shift in temperature), whereas the triggering factor for ‘two-stage’ and ‘sudden-forceful’ biting may not always be easy to spot.

A variety of underlying motivations have been suggested to explain why tail biting occurs, which emphasise the complexity of the behaviour. Due to the multifactorial origin of tail biting, the most effective preventive measure or intervention measure may differ between pens and between age groups of pigs. However, by reducing environmental stressors in general; both the chronic stressors and potentially acute stressors, will reduce the risk of tail biting.

2.3 Tail biting outbreak – a definition

Tail biting can suddenly and quickly develop within a group of pigs (Zonderland et al., 2011a) and when the behaviour intensifies, leading to more tail damaged pigs a tail biting outbreak is ongoing (Van de Weerd et al., 2005; EFSA, 2007). However, sometimes tail injuries may occur without the tail biting intensifies into an outbreak (Van de Weerd et al., 2005; Larsen, 2018). Pig producers therefore often report tail biting outbreaks as unpredictable and difficult to detect in the early stages (D'Eath et al., 2014).

One general and widely agreed definition of a tail biting outbreak does not exist. A number of peer reviewed publications using the term ‘tail biting outbreak’ and the belonging definition is listed in Table 2.1. Sometimes the term ‘tail biting outbreak’ has been applied without defining an outbreak (Scollo et al., 2013; Di Martino et al., 2015). Furthermore, some studies even distinguished between different kinds of tail biting incidences. Van de Weerd et al. (2005) distinguished between tail biting ‘incidents’ (at least one pig with fresh damage) and tail biting ‘outbreaks’ (three pigs with bleeding tail damage). Statham et al. (2009) distinguished between ‘underlying outbreaks’ and ‘severe outbreaks’ (see definitions in Table 2.1). As presented in Table 2.1 different criteria have been used to define a tail biting outbreak. The definitions of a ‘tail biting outbreak’ differed between studies in the number of affected pigs, wound freshness and tail damage severity.

Besides these different criteria used to define a tail biting outbreak, also the tail scoring method and tail scoring frequency will influence the prevalence of outbreak. If stock persons record pens with an outbreak during the daily management routines (Sinisalo et al., 2012) tails will likely not be inspected

Table 2.1. Summary of tail biting outbreaks definitions in peer reviewed publications.

Age group[1]	Group size	Tail damaged pigs per pen, %	Tail damaged pigs per pen, n	Tail damage definition in an outbreak	Reference
-	-	-	One pig	Bleeding wound	(EFSA, 2007)[2]
Weaners	10	20.0	Two pigs	Fresh wound and fresh wound/ bite mark	(Zonderland et al., 2008)
Weaners	12	8.3	One pig	Bleeding tail wound or tail loss	(Veit et al., 2017)
Weaners	12/ 24	8.3 or 4.2	One pig	Moderate damage	(Veit et al., 2016)
Weaners and finishers	14	7.1	One pig	Tail wound with infection	(O'Driscoll et al., 2013)
Finishers	6-20	-	-	Tail lesions	(Brunberg et al., 2011; Munsterhjelm et al., 2013b)[2]
Finishers	11	9.1	One pig	Tail wound	(Viitasaari et al., 2011)
Finishers	12	8.3	One pig	Fresh wound	(Van de Weerd et al., 2006)
Finishers	13-16	18.7-23.1	≥ three pigs	Bleeding damage	(Van de Weerd et al., 2005)
Finishers	14	7.1	One pig	Treated for tail damage	(Wallenbeck and Keeling, 2013)
Finishers	25-40	2.5 - 4	One pig	Bleeding wound	(Thodberg et al., 2018)
Finishers	30	6.7	≥ two pigs with severe damage[3] < two pigs[3]	Severe outbreak: severe damage (bleeding wounds and tail loss) Underlying outbreak: chewing damage/bite-marks	(Statham et al., 2009)
Finishers	35-40	≥ 20	7-8 pigs	Tail lesions	(Dippel et al., 2017)

[1] The age group 'Weaners' refer to pigs from approximately 7 to 30 kg, and 'Finishers' refer to pigs from approximately 30 kg until slaughter.

[2] A '-' indicates that the information was not given in the reference.

[3] Information is from Statham (2008).

as thoroughly, as if tails are scored by trained scientific personnel examining each tail individually (Statham et al., 2009). On the other hand, stock persons will observe pigs on a daily basis, while tails, due to lack of resources, will usually not be inspected individually by trained scientific personnel on a daily basis. If pens with a tail biting outbreak are the outcome of a study, the definition of a tail biting outbreak and tail scoring method will likely influence the outcome of both preventive and intervention studies.

The definition of a tail biting outbreak by EFSA (2007) stated that in the stage of a tail biting outbreak, biting will continue leading to several wounds. However, based on the present knowledge it is not possible to determine whether one bleeding wound equals ongoing tail biting, or if one bleeding wound can occur without a continuation in the biting. It could also be that tail biting is already ongoing in pens with scabbed wounds, and it is only the timing of the tail inspection that determines whether a bleeding wound is detected? If the presence of a bleeding wound is only a matter of tail inspection timing, then scabbed wounds should be included, especially if the aim is to identify the outbreak in the initial stages. In the early stages, tail biting may be ongoing, but the intensity of the behaviour is not followed by visible tail damage every time as discussed by Valros (2018). Therefore, to detect the early stages of a tail biting outbreak both scabbed and fresh wounds should be recorded. Furthermore, due to the potential for rapid escalation in tail biting within a group of pigs (D'Eath et al., 2014), tails should preferably be checked daily.

In the following when citing other studies, the term 'tail biting outbreak' is used, if the term is used in the cited literature.

2.4 The consequences of tail biting

Irrespective of the definition of a tail biting outbreak, it is broadly accepted that animal welfare and the presence of tail biting are closely linked (Schrøder-Petersen and Simonsen, 2001; EFSA, 2007; Valros, 2018).

There are different definitions of animal welfare. Broom (1991) defined animal welfare as how well an animal copes with the environment in which it is housed. Broom (1996) further argued that indicators of poor welfare are present if the animal has difficulties coping (adapting to conditions in which it finds itself) with the housing environment. If a pig cannot cope with the stressors present in the environment, it might start to tail bite. At the same time as discussed by Mason and Mendl (1993), other researchers argue that the animal feelings is the most important factor to estimate when determine the level of animal welfare. Using this definition, it is a sign of reduced animal welfare if the animal experiences an unpleasant mental state. A third way to assess the level animal welfare is based on the level of 'naturalness' in the environment. According to this view animals should have the opportunity to perform as much of their natural behaviour as possible (Fraser, 2009). Although different views on how to assess and define animal welfare (biological functioning, the affective state of the animal and natural living; Fraser (2009)) exist, they concur in the negative welfare consequence of tail biting.

As discussed in Section 2.3, in pens with tail biting the behaviour may escalate into a tail biting outbreak with several tail damaged pigs. If the behaviour is not stopped, victim pigs may lose the majority of the tail (Kritas and Morrison, 2004) and at worst, pigs may have to be euthanised, as discussed by Valros (2018).

Pigs exposed to tail biting have reduced welfare due to the pain connected with the actual behaviour and with the tail injury (EFSA, 2007). Pain, when defined as "an unpleasant sensory and emotional experience associated with actual or potential tissue damage" (IASP, 2017), caused by tail biting is, however, difficult to assess. This is due to the considerable variation in tail biting outbreaks – both in the number of affected pigs and severity of the wounds (scratches, wounds, partial tail loss, inflammation; discussed by Sutherland and Tucker (2011)). Di Giminiani et al. (2017) estimated the acute and long-term pain associated with tail damage by surgical amputating parts of the tail on 9-week and 17-week old pigs. Results indicated an increased sensitivity to mechanical pressure on the tail end up to four months after amputation.

Aside from increased sensitivity in the tail region, tail biting has also been reported to induce changes in behaviour (increasing activity (Statham et al., 2009) and lowered tails (Statham et al., 2009; Zonderland et al., 2009)), vocalization (Blackshaw, 1981), increased heart rate (Zupan et al., 2012), increased acute-phase proteins (Sutherland et al., 2009) and reduced growth (Sinisalo et al., 2012) as indicators of pain and reduced welfare. Furthermore, apart from the pain associated with the actual biting and the potential pain of a wound, a study reported signs of chronic stress amongst tail biting victims (Munsterhjelm et al., 2013a). These stress symptoms likely occur, if the victims cannot escape from the biting pig (EFSA, 2007; Zupan et al., 2012).

These findings all support the general assumption that tail biting is painful – both short and likely also long term. It has been speculated that the pain associated with tail biting might be about ten times as painful as being tail docked and last ten times as long (personal opinion by Bracke (2017)). In the estimation it was assumed that pigs were tail docked with a hot iron or similar with a minimum risk of subsequent infections compared to a tail injury caused by tail biting. Valros and Heinonen (2015) proposed a cost-benefit model to evaluate the welfare and economic costs of tail docking versus not docking. The model included the pain and workload (medication and time) related with tail docking versus tail damage due to tail biting and included the likely permanent improvement of housing conditions as preventive measures (more enrichment and space etc.) if pigs are not tail docked. These elements were included in an estimation made by D'Eath et al. (2016). The authors suggested that if housing, enrichment etc. were the same, tail docking would be better animal welfare than not docking if the total pain caused by tail biting was at least seven times worse than the pain caused by tail docking. However, if preventive measures such as more space and enrichment were provided for undocked pigs, the authors suggested that tail docking would only be better if the pain caused by tail biting was at least 31 times worse the pain caused by tail docking.

Beside the reduced welfare of tail damaged pigs and biting pigs, tail biting outbreaks are also a financial burden to the pig producer (D'Eath et al., 2016). At the abattoir, carcasses with a fresh or healed tail damage are in higher risk of total carcass condemnation (Valros et al., 2004; Harley et al., 2014), having abscesses (Huey, 1996; Valros et al., 2004), lower carcass weight (Harley et al., 2014; Carroll et al., 2018) and pleuritic lesions (Kritas and Morrison, 2007). Additional to the financial loss on carcasses, pig producers with tail biting problems also spend extra time on removing bitten pigs or the biter, adding extra enrichment material (Valros et al., 2016), and treating bitten pigs with antibacterial agents to avoid infections and systemic spread of bacteria (Fertner et al., 2017).

Altogether, previous studies suggest that tail biting influences the animal welfare negatively, is a financial burden to the pig producers and a severe tail injury is more painful for the individual than tail docking. However, it has not yet been established to what extent housing conditions need to be improved in order to counterbalance a higher prevalence of tail damaged pigs, when pigs are not tail docked, and thereby improve overall animal welfare.

2.5 Tail docking as a preventive measure

To reduce the risk of tail injuries and the pain associated with tail biting (Sutherland et al., 2009; D'Eath et al., 2016), most pigs within the EU are tail docked (EFSA, 2007). Tail docking reduces tail injuries, but the exact mechanism by which tail docking reduces tail damage is not clear (Sutherland and Tucker, 2011).

As with tail biting, the tail docking procedure is painful (Sutherland et al., 2008), and tail docking has been shown to affect pigs' behaviour both during the procedure and up to five hours post docking (end of the study period) in a study by Herskin et al. (2016).

When pigs are tail docked, neuromas are generated in the healed tail tip (Simonsen et al., 1991; Herskin et al., 2015) which have been linked with a decreased threshold to nociceptive pain. Nociceptive pain is pain arising from activation of nociceptors (a sensory receptor sensitive to injuries or painful stimuli) (IASP, 2017). It has been proposed that the neuroma formation in the tip of the tail makes victims more reactive to tail directed behaviour which reduce the risk of tail damage (Simonsen et al., 1991).

Another proposed theory is that tail docking reduces tail biting as pigs are less interested in a shortened tail compared to an intact tail (Simonsen et al., 1991; Feddes and Fraser, 1994). However, later studies comparing tail directed behaviour between tail docked and undocked pigs could not support this theory (leaving two-thirds of the tail - (Simonsen, 1995); leaving 50 % of the tail - (Paoli et al., 2016)). Paoli et al. (2016) speculated that the preventive effect of tail docking could be due to that a docked tail is more difficult to get a grip of, as the distal end of the docked tail can only be damaged by the incisor teeth, whereas if the tail is undocked, the biting pig can more easily get the entire tail in the mouth and chew it with the premolar teeth.

As discussed by Thodberg et al. (2018) very few studies have investigated the effect of different docking length on tail damage prevalence. A recently published study with finishers reported fewer pens with a tail damage incidence when pigs were tail docked (28 %; leaving 50 % of the tail) compared to pens with undocked tails (73 %) when reared in a research facility (Larsen et al., 2017). An epidemiological study by Scollo et al. (2016) reported a higher prevalence of tail damage on farms with half the tail docked (tipped) compared to short docked (more than half docked) in the weaner period. No relationship between tail damage and docking length was observed in the finisher stage. Thodberg et al. (2018) recorded the prevalence of tail biting outbreaks at four different docking lengths in four piggeries with finishers. Of the four included herds three reported tail biting problems. The docking lengths investigated were the same as in Herskin et al. (2015); intact tails, leaving 75 % of the tail, leaving 50 % of the tail and leaving 25 % of the tail. In the four herds included in Thodberg et al. (2018), the prevalence of tail biting outbreaks was significantly lower in the group with the shortest tails compared to the groups with longer tails. Furthermore, no difference in the prevalence of tail biting outbreaks was observed between undocked, leaving 75 % and leaving 50 % of the tail. These results indicate that leaving half the tail after docking does not reduce the prevalence of tail biting outbreaks compared to undocked tails. However, as discussed by Thodberg et al. (2018), their results should be interpreted with caution, as the number of pens with undocked tails in the study were reduced due to tail biting outbreaks in the weaner period, resulting in no 'undocked pens' in two of the four herds. Based on previous research it is therefore unclear whether docking half of the tail, which is the legal docking length in Denmark, reduces the prevalence of tail damage under conventional conditions in piggeries without tail biting problems among tail docked pigs.

Even though tail docking reduces tail biting, there is a ban on routine tail docking in the EU (2001/93/EC amendments to Directive 91/630EØF), and there is an increasing pressure from the EU Commission on member states to reduce the need for tail docking (EC, 2016). However, as concluded in an European Food Standards Agency scientific report a cessation of tail docking in today's production systems is expected to cause a dramatic increase in tail damaged pigs (EFSA, 2014). The report further concluded, before a cease in tail docking could be recommended, that more research is required on how to house and manage pigs with intact tails in conventional production systems.

2.6 Early detection of tail biting

Irrespective of whether pigs are tail docked or not, some tail biting outbreaks will occur as tail biting occurs in many different systems – including in enriched systems (Ursinus et al., 2014a; Alban et al., 2015). Therefore, to reduce the negative welfare impact of the behaviour it is desirable to detect and stop the tail biting in the early stages.

Earlier studies suggested some changes in behaviour prior to a tail biting outbreak such as increased activity (Statham et al., 2009; Zonderland et al., 2011b), increased restlessness (posture changes) (Zonderland et al., 2011b), increased tail-in-mouth behaviour (Schrøder-Petersen et al., 2003), increasing hanging or tucked tails (Statham et al., 2009; Zonderland et al., 2009; Ursinus et al., 2014a), increased exploratory behaviour (Zonderland et al., 2011b; Ursinus et al., 2014a) and a tendency to altered eating behaviour (Wallenbeck and Keeling, 2013). Larsen et al. (2016) discussed methods to detect future tail biting outbreaks based on behavioural changes and concluded that the best approach would be to monitor behaviour at pen level, as the behaviour of the individual pig is not consistent over time (Ursinus et al., 2014a; Paoli et al., 2016).

Altogether, previous findings indicate a change in behaviour before a tail biting outbreak, but it is not evident if these changes can be detected at the pen level, and whether the behaviour changes to a point where it can be used to predict tail biting outbreaks. This research area, therefore, needs further investigation.

2.7 Preventing tail biting outbreaks

If tail biting outbreaks can be identified in advance based on behavioural changes, it opens the possibility of conducting an intervention in high-risk pens, and thereby prevent or at least reduce actual tail biting outbreaks.

The most studied tail biting risk factor is the impact of access to enrichment materials. Newberry (1995) defined enrichment as “environment modifications that improve the biological functioning of animals”. Improvements in biological functions could be improvements in health, growth, physiological systems or behavioural systems (Fraser et al., 1997). In the scope of this thesis enrichment was provided to give pigs extra materials to explore and thereby reduce tail biting.

Several studies reported that straw provided on the floor reduce the risk of tail biting outbreaks (Van de Weerd et al., 2005; Scott et al., 2007; Zonderland et al., 2008; Courboulay et al., 2009). Other enrichment materials or increasing levels of enrichment have also been reported to reduce tail damage, such as compost in a rack vs no enrichment (Beattie et al., 2001), straw and wood shavings vs none (Munsterhjelm et al., 2009), chain with plastic toy and jute sack vs chain with plastic toy (Ursinus et al., 2014b), a larger amount of wood shavings and straw vs two handfuls of wood shavings (Ursinus et al., 2014a) and dried corn silage or alfalfa hay vs plastic stick, plastic ball and hardwood sticks (Veit et al., 2016).

As discussed in Section 2.2, Taylor et al. (2010) suggested different underlying motivations causing the tail biting. When providing pigs with extra enrichment, the enrichment meet some of the pigs’ behavioural needs for explorative behaviour (Studnitz et al., 2007) and this reduces the risk of tail biting.

In the enrichment studies mentioned above, pigs had access to the material throughout the entire study period. Another approach to eliminate tail biting could be to supply extra enrichment to pens at risk of a tail biting outbreak. Only providing the additional enrichment material in high-risk periods ensures novelty which besides destructibility, edibility, complexity and manipulability is an important feature to keep pigs interested in the material (Studnitz et al., 2007). Furthermore, if extra enrichment is only provided in high-risk periods, less material is needed, and this would decrease the challenges with litter materials blocking the slurry pipes (D'Eath et al., 2014). This approach might overall reduce the severity and the number of tail damaged pigs, because the small amount of material is more easily handled, which increases the likelihood of the farmer to look for the early signs of tail biting and providing the material to high-risk pens.

Thus, it is relevant to investigate, if pens with a future tail biting outbreak can be identified and whether providing these pens with extra enrichment right when the biting has started can prevent actual tail biting outbreaks.

2.8 How to stop a tail biting outbreak

If the tail biting is not identified until a tail biting outbreak is ongoing, it is essential to stop the behaviour as quickly as possible to minimise pain, reduce tail loss and subsequent infections in the bitten tails. Only a few studies have investigated the effect of different intervention strategies in pens with tail biting outbreaks. Zonderland et al. (2008) reported that removing the biting pig or giving a small amount of straw on the floor (20 g/pig/day) stopped the biting behaviour to the same extent in the following ten days. However, fresh wounds still occurred ten days after the intervention irrespective of the intervention (11 % on day 10 vs 25 % on day 0, $P < 0.1$). This suggests that the treatments did not completely stop the tail biting.

Removing the biting pig as an intervention during an outbreak has also been reported in three farmer surveys. In a Dutch survey, farmers rearing tail docked pigs most frequently reported ‘removing biters’ and ‘removing bitten pigs’ as interventions when tail damaged pigs occurred (Bracke et al., 2013). These results are in line with a Finnish and a Swedish farmer survey. In these surveys, the three most frequent interventions in pens with tail damaged pigs were: identifying the biter/remove biter, providing extra litter material (straw, wood-shavings etc.) and remove bitten pigs (Valros et al., 2016; Wallgren et al., 2016).

As previously addressed, if pigs are not tail docked, more tail biting outbreaks are to be expected. Providing extra enrichment, especially straw, has been reported to reduce tail damage in several studies. However, in many of the current production systems, litter material, such as straw, can only be handled in small amounts due to slurry system constructions (D'Eath et al., 2014) and it is only practicable in pens with solid floor. In systems without solid floor supplying pens with a hanging enrichment device could be a way to stop the tail biting. However, so far no experimental studies have examined the effect of hanging materials on tail damage in pens with a tail biting outbreak (D'Eath et al., 2014). It is therefore unclear whether a hanging material is as effective as a litter material to stop the tail biting when provided in pens with a tail biting outbreak.

2.9 Project aim and hypotheses

In the coming years, due to the EU Commissions pressure on member states to reduce the need to tail dock, more pigs are expected to be reared with undocked tails in conventional piggeries. This shift from rearing tail docked to undocked pigs will likely increase tail damaged pigs dramatically if housing systems and management routines are not adjusted to the increased risk of tail biting. Even with a focus on minimising risk factors tail biting will still sometimes occur, because of its multifactorial origin. To reduce the negative welfare impact caused by tail biting, it is important to identify the behaviour in the early stages, bringing the behaviour to a stop and thereby avoiding severe tail biting outbreaks.

This PhD project aimed to reduce the need to tail dock by investigating: 1) The consequence of not tail docking pigs in current production systems, 2) If tail biting outbreaks can be identified based on behavioural changes and 3) If providing enrichment, applicable in current production systems, can stop the tail biting once started.

Specific aims

To fulfil the main objective four specific objectives were defined to determine: 1) The prevalence of tail damage among pigs with undocked tails at a, when it comes to tail biting, low-risk piggery which usually tail docks, 2) If behavioural changes occur prior to a tail biting outbreak, 3) If extra enrichment provided to pens with upcoming tail biting outbreak can stop the tail biting and 4) Which enrichment intervention strategies, applicable in current production systems, most efficiently stop the tail biting in pens with a tail biting outbreak.

Hypotheses

The following hypotheses were prepared to meet the four specific aims.

Hypotheses, study I (specific aim 1- Paper I)

- The prevalence of tail damaged pigs is substantially higher in pens with undocked pigs than in pens with pigs that have half the tail docked in a conventional piggery
- More pigs with undocked tails will receive a tail lesion remark at the abattoir than tail docked pigs
- Growth stage will affect the prevalence of tail damage

Hypotheses, study II (specific aim 2 – Paper II)

- Behavioural differences occur between pens with an upcoming tail biting outbreak and pens without a tail biting outbreak. In upcoming pens with a tail biting outbreak, the activity level is expected to be higher, more tails are hanging, fewer pigs will be at the feeder and more pigs are performing exploratory behaviour, pen mate directed behaviour and tail directed behaviour than in control pens.

Hypothesis, study III (specific aim 3 – Paper III)

- Providing pens with either straw on the floor, haylage in a rack or rope lying on the floor when the first tail injury is observed reduces the risk of a tail biting outbreak compared to pens without extra enrichment added (control pens)

Hypothesis, study IV (specific aim 4 – Paper IV)

- Straw provided on the floor or rope lying on the floor prevents a further escalation in tail injuries better than a Bite-Rite in pens with a tail biting outbreak

3. Material and Methods

To address the hypotheses four experiments were conducted in two different conventional Danish piggeries. This section contains a general description of how the experiments were carried out.

3.1 Study I – Tail damage prevalence and abattoir recordings, docked vs undocked (Paper I)

The aim of study I was to investigate the consequences of not tail docking on tail damage prevalence at an expected low-risk tail biting piggery.

Power calculation and sample size

In study I, the probability of tail damaged pigs in pens with docked tails were set to 5 % and 25 % in pens with undocked tails. To attain a power of 80 % and a significance level of 5 %, there was a need of 50 pens per group.

Experimental herd

Because the aim of the study was to investigate the consequence of not tail docking on tail damage in a low-risk tail biting piggery, the piggery was, among other things, chosen based on a low prevalence of tail lesion remarks at the abattoir among tail docked pigs. In the year prior to the study, 0.37 % of the pigs received a tail lesion remark according to criteria applied at the abattoirs routine meat inspection (DVFA, 2011). Furthermore, the piggery was chosen because the farmer and his advisor infrequently experienced tail lesions at the piggery. Based on documented risk factors associated with tail biting (Taylor et al., 2012) the housing system was considered a low-risk system due to the daily provision of straw, low stocking density during rearing, solid floor in the lying area and optimized feeding (in accordance with Danish recommendations (Tybirk et al., 2016)). In addition, prior to the data collection the automatically controlled ventilation system was inspected and adjusted by a professional ventilation consultant employed by SEGES, Danish Pig Research Centre.

Animals and housing

The study included 960 undocked pigs and 962 tail docked crossbred DanBred pigs (Danish Duroc x (Landrace x Yorkshire)) housed in 47 and 48 pens respectively. Pigs were born in traditional farrowing pens with crates, and they were ear-tagged just before weaning and weaned at 26 days of age (SD 2.3). On the day of birth piglets got the needle teeth removed by grinding and four days after farrowing male piglets were castrated surgically and half the tail was docked on piglets in the 'docked group'. Just before castration male piglets were given a short-term analgesic, and on day 4 all piglets were given an iron injection (Uniferon; Pharmacosmos, Holbæk, Denmark). After weaning, but before transported to the experimental farm, pigs were housed for two days in pens with two climate zones at the sow facility. The pens had solid floor, cover in the lying area and slats in the dunging area. Pigs had ad libitum access to feed (Danstart VP30; Vilomix, Mørke, Denmark).

At the experimental farm 20 pigs (SD 1.46) were randomly allocated to a pen, where they remained until slaughter. Docked and undocked pigs were housed in separate pens within the same room. Within the first two weeks after arrival, the stockperson moved one or two of the smallest pigs from each pen to a buffer pen, at which point these pigs were excluded from the experiment.

The pens were typical Danish two-climate pens with solid floor in the lying area and *ad libitum* access to feed in a dry feed dispenser (Figure 3.1). Information on feed mixtures can be found in Paper I (Table 1). Two adjacent pens shared two nipple drinkers placed in each side of the feeder. The water flow was not checked along with the study, but it was checked regularly by the stockperson. In each pen, two vertical wooden pine boards stood in a retainer on the floor (See schematic drawing of pen design in Paper I). Pigs were also provided daily with chopped wheat straw on the floor (~ 230 g/pen/day). In cases where pens were soiled due to defecation the straw allocation stopped. This could occur when pigs weighed around 70 kg. In each of the four identical rooms at the piggery 6 to 13 pens were included in the study. The climate was regulated by a negative pressure ventilation system (SKOV A/S, Glyngøre, Denmark) supplemented with ceiling air inlets (Figure 3.1). Air inlets opened when room temperature was 2 °C above the set temperature. On the day of arrival the set temperature

Figure 3.1 Room overview and pen design.

was 24 °C. The temperature was gradually decreased during the growth period ending at 17 °C on day 112 (approx. 90 kg liveweight).

The stockperson checked the pigs twice a day; at around 0900 and 1730h. If needed according to the herd veterinarian's recommendations, pigs with clinical signs of disease were treated and recorded by the stockperson. If necessary according to the advice of the veterinarian, pigs with health problems were moved to a hospital pen.

In pens with clinical injured tails the daily provision of straw was doubled (~ 460 g/pen/day) and a plastic enrichment device with four protruding chew sticks (Bite-Rite; Ikadan Systems A/S, Denmark, http://www.ikadan.dk/Default.aspx?ID=3195) was suspended in the middle of the pen (Figure 3.11). Pigs with signs of infection in the tail (swollen red tissue) were treated with antibiotics and pigs with severe tail injuries, defined as half the tail or more missing, were moved to a hospital pen.

Measurements

Every second week from weaning until slaughter tails were inspected and scored at pig level using the four parameters (tail damage, tail length, wound freshness and tail swelling) listed in Table 3.1. A pig could be scored with tail damage more than once during the growth period. At tail inspection, the average weight of the pigs was evaluated visually.

Table 3.1 Tail injury scoring system (modified after Kritas and Morrison (2004) and O'Driscoll et al. (2013)).

Tail scoring	Description
Tail damage	
No	No visible tail lesion. Earlier lesion is healed.
Red, clean and/or minor scratches	Tail appear red and/or has minor scratches
Tail wound	Visible wound with obvious tissue damage
Tail length[1]	
Intact	Full length tail
Part missing	A part of the tail is missing
Wound freshness	
Fresh/ bleeding	Fresh blood is visible
Dried/ scab	Tail wound covered with a scab
Swelling	
No	No swelling
Yes	Swollen red tail indicating an infection

[1] Tail length was only recorded on undocked pigs.

At the abattoir damaged tails were recorded in the same way as described in Alban et al. (2015). Every pig was inspected during the routine meat inspection by trained veterinarians or technicians according to the Danish meat inspection circular (DVFA, 2011).

Data management and statistical analysis

Statistical analyses were performed using SAS Enterprise Guide 7.1 (SAS Institute Inc., Cary, NC, USA) with significance level of $P < 0.05$ and tendency level of $P < 0.10$.

Pigs scored with tail damage were categorized as tail biting victims. In study I, the tail damage prevalence was calculated both at pen level and overall individual level. The pen level calculation estimated the average number of affected pigs per pen and affected pens, whereas the overall calculation at the individual level across pens stated the amount of tail injured pigs.

To compare differences between age groups on tail damage, undocked pigs were divided into three growth stages: weaning (7 to 30 kg, 5 to 12 weeks), grower (30 to 60 kg, 13 to 17 weeks) and finisher (60 to 90 kg, 18 to 21 weeks). The effect of weight (age) on tail damage prevalence (binary variable) was analysed using the GLIMMIX procedure with weight as fixed effect and sex, batch and pen as random effects. Differences between number of docked and undocked pigs receiving a tail biting remark at the abattoir was analysed using a χ^2-test.

3.2 Study II – Behavioural changes before a tail biting outbreak (Paper II)

The aim of study II was to examine if changes in behaviour could be identified in pens with an upcoming tail biting outbreak. This was done by comparing the recorded behaviours between control pens and upcoming pens with a tail biting outbreak. A tail biting outbreak occurred at the pen level when at least four pigs had a tail injury (see description below).

Power calculation and sample size

Earlier studies (see Section 2.6) suggested that the behaviour of the pigs change prior to a tail biting outbreak. The most well-established behavioural change within the last days prior to an outbreak, is the shift in tail posture from curly to tucked. A study reported at the individual level that with a tucked tail the risk of a tail injury was 22 % two to three days later, whereas with a curled tail the risk was 9 % (Zonderland et al., 2009).

Previous studies investigating if behavioural changes occur in the days prior to a tail biting outbreak have most often been conducted with the individual as its own control (Larsen et al., 2016), whereas no studies have investigated if behavioural differences can be observed at the pen level in the days prior to an outbreak. The differences reported in previous studies at the individual level therefore had to be converted to the pen level.

The power calculation for study II was based on the assumption that some variation in the recorded behaviours' would occur between control pens and upcoming pens with a tail biting outbreak. As, the objective was to detect the outbreak in the early stages, the behavioural differences between pens would likely not be as pronounced, as if more severe outbreaks had to occur before a comparison was made. The assumption was that the prevalence of tucked tails would be doubled in pens close to an outbreak according to the findings by Zonderland et al. (2009).

Based on these considerations, it was assumed that in 30 % of the control pens the behaviour characteristic of pens with a tail biting outbreak would occur without a subsequent tail biting outbreak, and in 60 % of the pens with a tail biting outbreak the behaviour characteristic of a future outbreak would occur. With this assumption 100 pens were needed to obtain a significance level of 5 % and a power of 86 %. It was further expected that a tail biting outbreak would occur in approximately half the pens.

Experimental herd

Study II, III and IV were conducted in the same Danish conventional piggery, which was different to the one used in study I. Study II and IV included the same subjects and were carried out from November 2015 to February 2016 (Figure 3.2). Study III was carried out from November 2016 to February 2017 (Figure 3.3).

Animals and housing

Study II included 2,301 undocked nursery pigs from 6 to 30 kg (four farrowing batches and 222 litters) born in farrowing pens, where the lactating sow was kept loose (for pen design details, see Pedersen et al. (2015)). A system with loose lactating sows was chosen, as that is how sows are expected to be housed in Denmark in the future. Furthermore, with a loose sow in the lactation period, the piglet's housing conditions were likely improved due to more social interaction with the sow (Chidgey et al., 2016) and better access to the udder than in a system with crates (Pedersen et al., 2011).

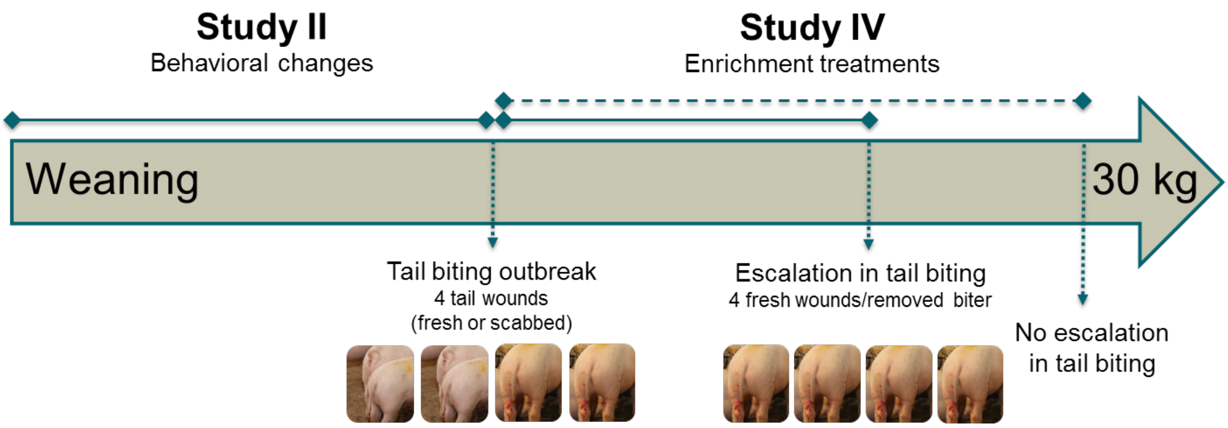

Figure 3.2 Overview of data collection in study II (Paper II) and study IV (Paper IV). In study II differences in behaviour prior to an outbreak were investigated, and in study IV the effect of providing different kinds of enrichment on tail damaged pigs was investigated in pens with a tail biting outbreak.

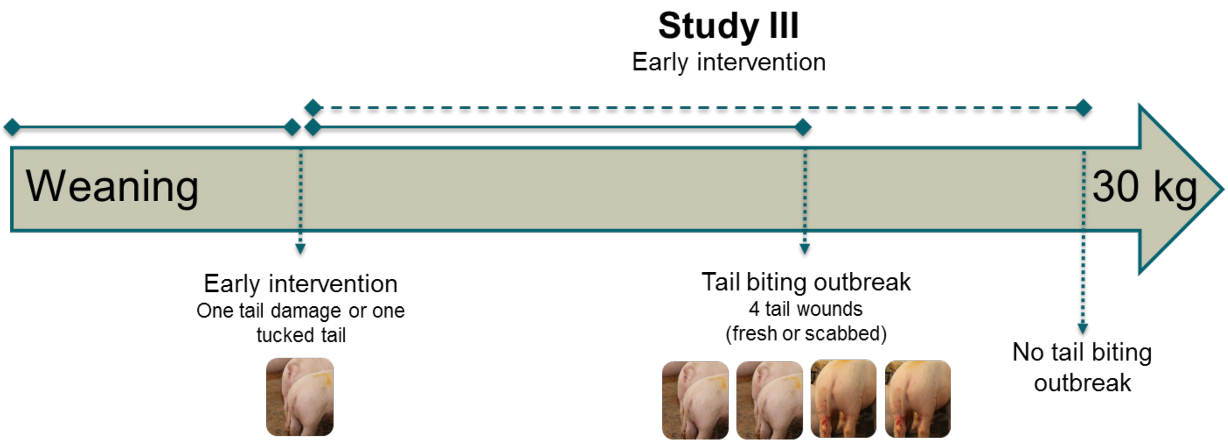

Figure 3.3 Overview of data collection in study III (Paper III). In study III the effect of an early intervention with an enrichment material on the prevalence of tail biting outbreaks was investigated.

Pigs were crossbreeds of (Danish Duroc x (Landrace × Yorkshire)), and male piglets were castrated surgically three or four days after farrowing. Iron injections (Uniferon, Pharmacosmos, Holbæk, Denmark), teeth grinding of the needle teeth (Tandsliber proff, Hatting, Horsens, Denmark) and surgically castration of male piglets with a scalpel were carried out on day three or four after farrow. Male piglets were given analgesic just before castration (Melovem® 5 mg/ml). Approximately 14 days after farrowing piglets were offered solid feed on the floor and had access to the straw the sow pulled from the straw rack. Two days before weaning, pigs were ear tagged, individually weighed and their sex was noted. The lactation period was 27.7 days (SD 2.9) and pigs weighed 5.8 kg (SD 1.5) at weaning. After weaning pigs were transported to the nursery facility close to the sow facility

(1.5 km). Pigs were individually weighed again at the end of the study before moved to the finisher location.

Upon arrival to the weaner unit pigs were sorted by size into pens with 31 pigs per pen (SD 1.5; 0.34 m^2/pig). Pens were designed as traditionally Danish two-climate pens with solid floor and a cover in the lying area (Figure 3.4). The cover was opened on day 21 after arrival to the weaner unit. Two

Figure 3.4 Room overview and pen design.

adjacent pens shared two nipple drinkers placed in each side of the feeder and a drinking bowl was placed in each pen at the pen wall above the slatted floor. The water flow was not checked along with the study, but it was checked regularly by the stockpersons. Pigs had *ad libitum* access to feed in a dry feed dispenser (MaxiMat, Skiold A/S, Sæby, Denmark) with six eating places per pen giving approximately five pigs/eating space. Pigs were fed with three different home-mixed commercial compound diets from 6 to 30 kg. Phase one diet allocated from approx. 6 to 10 kg (17.4 % crude protein) consisted of 64.0 % wheat, 20.0 % premix including minerals and vitamins (HeavyPig 3 20 %, Vilomix, Mørke, Denmark), 10.5 % fish meal, 3.5 % soy oil and 2 % toasted soy bean. Phase two diet was allocated from approx. 10 to 15 kg (18.1 % crude protein) and consisted of 44.4 % wheat, 25.0 % barley, 15.0 % toasted soy bean, 8.2 % premix including mineral and vitamins (MIN 27600, Vilomix, Mørke, Denmark), 5.0 % fish meal and 2.4 % soy oil. Phase three diet was allocated from approx. 15 to 30 kg (18.4 % crude protein) and consisted of 48.8 % wheat, 25.5 % toasted soy bean, 20.0 % barley, 4.2 % premix of mineral and vitamins (MIN 27603, Vilomix, Mørke, Denmark) and 1.5 % soy oil. The shift between diets depended on the average bodyweight at the pen level estimated at weaning and the shift was gradually conducted over a 7 or 14-day period. Each pen was equipped with two wooden blocks hanging from a chain not touching the floor to ensure permanent access to manipulable material according to Danish legislation (MEFD, 2017). In addition, pens were provided daily with one scoop (~ 350 g) of very fine chopped straw (Easy Strø, Dansk Dyrestimuli, Nykøbing Mors, Denmark, http://easy-stroe.dk/files/easy-str%c3%b8_UK.pdf, Figure 3.9) throughout the study period.

The rooms were ventilated by a negative pressure air flow through wall air inlets on one side of the building (SKOV A/S, Glyngøre, Denmark). The room temperature at weaning was 24 °C and it was gradually lowered to 19 °C on day 42. Thermostatically controlled floor heating pipes were placed in the floor in the lying area giving a floor temperature of 30 °C at the start of the study. The floor heating was turned off on day 14.

During the stockpersons' daily inspection, pigs with clinical signs of disease were treated with antibiotics when needed and if necessary moved to a hospital pen according to the herd veterinarian's recommendations. Pigs with severe tail lesions (more than half the tail missing or swelling as a sign of infection) were moved to hospital pens. The pigs were individually weighed two days before moved to the finisher facility. Pigs moved to hospital pens were not weighed.

Measurements

Defining a tail biting outbreak

The candidate wanted a definition of a tail biting outbreak where the outbreak was detected in its early stages before severe damages occurred (tail loss). To ensure relevance in practise it was also essential with a definition where it was highly likely that the tail biting would escalate if an intervention was not conducted.

Given the many different definitions of a tail biting outbreak in previous studies, a minor pilot study was conducted at the experimental piggery in four pens before the primary data collection (unpublished). In the pilot study, tails were scored three times weekly (in the same way as in the main study) from weaning and throughout the rearing period. No statistical evaluation was performed to decide on a definition of a tail biting outbreak. The definition was based on tail scorings, causal observations and previous studies (see Section 2.3).

Based on the pilot study a tail biting outbreak was in study II-IV defined as occurring when at least four pigs had a tail wound, which was more severe than scratches (~ 13 % of the pigs/pen). A wound was included irrespective of the freshness (scabbed or fresh). As with 'wound freshness', 'tail length' was not included in the definition of a tail biting outbreak. It was only the severity of the actual lesion that was included. A description of a 'wound' can be found in Table 3.2.

It was the candidate's experience from the pilot study that using this definition would mean that tail biting was likely to continue leading to more tail damaged pigs, but at the same time only a few pigs would suffer from tail loss on the day of the outbreak. Based on the pilot study, it also became evident that by scoring pigs three times weekly, pens with an upcoming tail biting outbreak could be detected in the early stages prior to tail loss. When the term 'tail biting outbreak' is applied in the following along with the conducted studies, it reflects the definition described above (at least four pigs with a tail wound irrespective of wound freshness).

Tail scoring prior to tail biting outbreak

In the farrowing section litter origin, weight, sex and the presence of tail damage according to Table 3.2 were recorded the individual level two days prior to weaning (Figure 3.5).

Figure 3.5 Ear-tagging, weighing, sex noting and tail scoring in the farrowing room just before weaning.

After weaning, the tails were scored three times weekly until a tail biting outbreak occurred. At tail scoring a person entered the pen and inspected the tails. If tail damage was observed, the ear-tag number and the type of injury was recorded according to the criteria listed in Table 3.2. The picture-based scoring sheet used during tail scoring, corresponding to the description in Table 3.2, is included in the Appendix.

Tail posture

Three times weekly (Monday, Wednesday and Friday) tail posture (curly, hanging or tucked) was recorded from outside the pen on standing pigs (Figure 3.6). Tail posture was recorded from weaning and until a tail biting outbreak.

Table 3.2 Tail injury scoring system.

Tail scoring	Description
Injury size/ severity	
None	No visible tail injury. Any earlier injuries have healed
Minor scratches	Minor superficial tissue damage (scratches)
Wound	Visible wound with tissue damage larger than a few millimetres in diameter
Wound – tail end will fall off	The outer part of the tail has almost been bitten off. During healing the tail tip will fall off
Injury freshness	
Intact scab	The injury is covered with a hard-dry scab
Not intact scab	The injury is covered with a scab, but cracks in the scab and dried blood/fresh tissue are visible
Fresh damage – not bleeding (weeping)	Skin is broken, no scab, no blood – only weeping.
Fresh damage - bleeding	Fresh injury and fresh blood are visible
Tail length	
Intact	Full length tail
Outer part is missing	The outer part but less than half of the tail is missing
More than half is missing	More than half of the tail is missing
< 1 cm left of the tail	Less than 1 cm of the tail is left
Swelling	
No	No swelling
Yes	Swollen red tail indicating an infection

Figure 3.6 Pictures illustrating a curly (left), hanging tail (middle) and tucked tail (right).

Video recording

An overhead video camera (Dahua 2MP HD IR Dome, Dahua, Haarlemmermeer, Netherlands) was mounted above each pen, timed to record daily from 0700 to 2100h. This time period was chosen as previous studies reported that pigs are most active in the daytime (Beattie and O'Connell, 2002). Video data was collected from weaning until a tail biting outbreak.

A pilot study recording pigs' behaviour including ten pens with a tail biting outbreak was conducted to determine the sampling method for the main study. Pig behaviour and tail posture were recorded using scan sampling on day -13, -10, -7, -4, -3, -2 and -1 prior to the day of the outbreak (day 0). Due to poor video quality, tail posture could not be recorded in the three pens originating from batch one, leaving seven pens with tail posture recordings in the pilot study. Visual inspection of the recorded data suggested (Appendix Figure A1-A4) that changes in tail posture (Figure A1) occurred within the last three days prior to the tail biting outbreak. It was therefore decided to conduct the behavioural recordings on the last three days prior to an outbreak. In line with Beattie and O'Connell (2002) the pilot study results further indicated the highest level of activity in the morning hours (0800-1100 h) and in the late afternoon (1700-2000 h; Figure A4). These time periods were therefore chosen for the behavioural recordings in the main study, because due to restricted time for video observations it was not possible to record the behaviours throughout the day. As the aim of the study, based on the literature review, was to investigate if there were a difference between activity, pigs at the feeder, explorative behaviour, tail directed behaviour and tail posture, the periods with the highest level of activity was chosen to get as many pigs as possible included at each observation time.

Behavioural recordings on video

Prior to a tail biting outbreak, behaviour was recorded in pens with an upcoming tail biting outbreak (tail biting; T-pens) and in pens without a tail biting outbreak within the next seven days (control; C-pens). Tail biting outbreaks developed between 9 to 49 days after weaning (Figure 4.1). Therefore, to avoid age affecting behaviour, T-pen and C-pen were randomly paired within room. This ensured that pigs within a pair of pens (T-pen and C-pen) originated from the same farrowing batch and were at the same age on the recording days. A pen could be used as a control pen, if a tail biting outbreak did not occur within the following seven days calculated from the day of the tail biting outbreak (day 0) in the T-pen. Applying this method, a pen could be used as a C-pen and then later become a T-pen depending on the onset of the tail biting outbreak in the pen.

Based on the pilot study and previous studies investigating behavioural changes prior to an outbreak (see Section 2.6), it was decided in the main study to record pigs' behaviour and tail posture on day -3, -2 and -1 prior to a tail biting outbreak (T-pen) using scan sampling every half hour between 0800-1100 h and 1700-2000 h. On the same dates for comparison, the same behaviour and tail posture were also recorded in a randomly matched control pen (C-pens). The principle of the behavioural recordings is presented in Figure 3.7. At each observation time, the number of pigs performing the

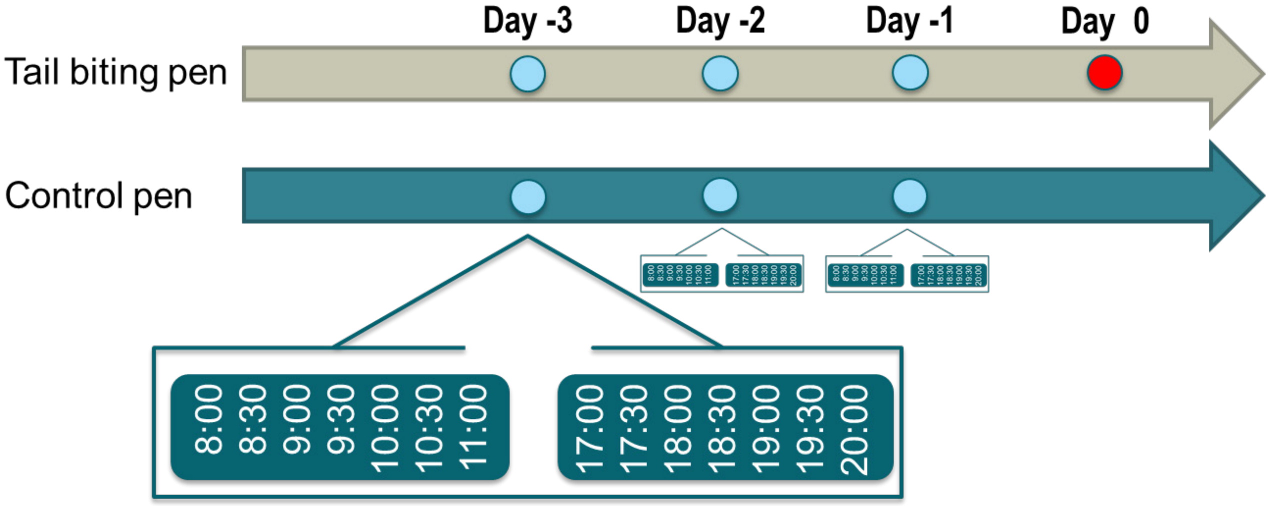

Figure 3.7 Behaviours and tail posture listed in Table 3.3 were recorded in control pens and upcoming pens with a tail biting outbreak on day -3, -2 and -1 prior to an outbreak. Measures were recorded using scan sampling every half hour between 0800-1100h and 1700-2000h.

behaviours described in Table 3.3 was noted. The activity measure included all standing and walking pigs irrespective of what the pigs were doing. Pigs at the feeder included all pigs standing within one pig's length away from the feeder and within this area a pig could take one of the postures; nose in trough, head against feeder, head away from feeder or nose solid floor at feeder (see description in Table 3.3). Furthermore, the number of standing, walking and sitting pigs engaged in nosing the enrichment device (hanging wooden sticks), the solid floor or the slatted floor (outside feeder area), nosing the body or nosing the tail region of a penmate was recorded. Tail posture was recorded on all standing pigs. If the position of the tail was not visible due to the camera angle, tail position was recorded as 'tail-not-shown'.

The recorded behaviours and their definitions were quite simple. The behaviour of lying pigs could have been included. However, using a simpler definition (easy to see), the measured behaviours could, if any difference was observed, more likely be implemented in practise or in future software programmes automatically recording these behaviours.

The cover above the lying area was permanently opened on day 21. When the cover was down, it was not possible to see pigs beneath the cover. However, the cover was opened on the same day in all the pens within a room, making the visible area the same in each pair consisting of a control and tail

Table 3.3 Ethogram for behaviours recorded on video (modified after Zonderland et al. (2011b)).

Behaviour	Description
Pigs standing or sitting	
Standing/walking	Pigs are standing still or moving around.
Sitting	Pigs sitting. Body is supported by hind-quarter and the front legs are straight.
Pigs at feed dispenser	
Nose in trough	Pigs with the nose in the feeding trough.
Head against feeder	Pigs less than one pig length away from the trough with the head oriented towards the feeder. The head is not in the trough, and pigs are not rooting the floor.
Head away from feeder	Pigs less than one pig length away from the feeder with the head oriented away from the feeder.
Nose solid floor feeder	Pigs touching, sniffing, rooting or licking the solid floor within one-pig-length from the feeder.
Pigs at drinking bowl	
Drink or nose the drinking bowl	Pigs with the nose in the drinking bowl or pigs with the head close to the drinking bowl sniffing, touching, rooting or biting the drinking bowl.
Pigs nosing enrichment, floor or pen-mate	
Nose enrichment	Touching, sniffing, rooting or biting the enrichment.
Nose solid floor	Touching, sniffing, rooting or licking the solid floor.
Nose slatted floor	Touching, sniffing, rooting or licking the slatted floor.
Nose tail region/ rear end of the pig	Touching, sniffing, rooting, chewing or biting the tail region or immediate surroundings.
Nose pen-mate, body	Touching, sniffing, rooting, chewing or biting other part of the body beside the tail region.
Tail-in-mouth	Chewing, sucking or biting a pen-mate's tail.
Tail posture on standing pigs	
Curly tail	Tail is curly.
Tucked tail/ hanging tail	Tail hanging or tucked into the body.
Tail other	Other tail posture not included in the above mentioned, for example sticking straight out.
Tail not shown	Tail posture is not visible.

biting pen. In total 56 of the 74 pens were included in the video study. Due to poor quality of the video recordings the 18 pens from batch one had to be excluded.

Data management and statistical analysis

Statistical analyses were performed using SAS Enterprise Guide 7.1 (SAS Institute Inc., Cary, NC, USA) with significance level of $P < 0.05$ and tendency level of $P < 0.10$.

The outcome variable was tail biting outbreak at the pen level in study II-IV. Tail biting outbreak is traditionally measured at pen level (See Section 2.3, Table 2.1), as the behaviour can quickly spread within a group of pigs (reviewed by D'Eath et al. (2014)), but does not necessarily spread between pens. The pen was therefore the experimental unit in study II-IV.

Tails down (sum of hanging and tucked tails), pigs at feed dispenser (sum of all behaviours recorded at the feed dispenser; Table 3.3), pigs performing explorative behaviour (sum of nosing enrichment, nosing solid floor and nosing slatted floor; Table 3.3), pigs performing pen mate directed behaviour and tail directed behaviour (sum of tail-in-mouth and nosing tail region; Table 3.3) were calculated as the percentage of standing pigs at each scan. Data on pigs at the drinking bowl were not analysed due to low prevalence. The overall activity was calculated as the percentage of standing and sitting pigs of the total number of pigs in the pen.

Behavioural and tail posture differences between T-pens and C-pens were analysed using the GLIMMIX procedure with group (T-pens vs C-pens), time of day (morning vs afternoon), day before outbreak (day -3, -2 and -1), days post wean (day 9 to 17, day 18 to 26, day 27 to 35, day 36 to 45) as fixed effects and pairs of pen (T-pen with C-pen) as a random effect. An interaction between group and day was fitted with regards to the outcome of percentage of tails down. All other interactions between group and fixed effects were non-significant and were removed from the models.

Tail scoring and direct observations of tail posture were performed three times weekly (on Mondays, Wednesdays and Fridays). Therefore, depending on the day of the week of the tail biting outbreak, the previous tail posture recording was carried out either two or three days earlier. Thus, in the statistical model, tail posture recorded on day -3 and -2 were grouped in one category; -3/-2. The same categorizing principle was used for day -5/-4 and day -7/-6. Tucked tails and hanging tails were pooled into one category termed ‘tails down’. Direct observations of tail posture in pens with an upcoming tail biting outbreak were analysed by GLIMMIX with repeated measurements at pen level and ‘number of active pigs’ and day as fixed effects.

The effect of the number of tail damaged pigs on day 0 (pen level categorization: 4 to 5 injured tails, 6 to 8 injured tails or >8 injured tails) on the percentage of tails down based on video recordings on day -3, -2 and -1 were analysed using GLIMMIX with injured tails on day 0, day before outbreak and time of day as fixed effects and pen as random effect.

Pigs scored with a tail wound or scratch at least once after weaning were characterized as a victim (binary variable). The effect of litter origin on the risk of becoming a tail biting victim was analysed using GLIMMIX with victim at weaning, litter origin and weaning weight as fixed effects. Pen and batch were included as random effects. Correlation between average weaning weight (mean) at the pen level and the onset of a tail biting outbreak (days post weaning) was analysed using the correlation procedure (PROC CORR).

3.3 Study III – Effect of early intervention (Paper III)

The aim of study III was to examine if providing extra enrichment as early intervention (just when the biting had started) could stop the tail biting and prevent tail biting outbreaks.

Power calculation and sample size

The effect of an early intervention was examined in study III. It was assumed that if the early intervention could stop the tail biting (three treatment groups), the number of pens with a tail biting outbreak should be reduced by 70 % when compared to pens with no intervention (control pens). With this anticipated effect of the early intervention, including 50 pens in the study, 10 pens per intervention group and 20 pens as control would result in a power of 95 % and a significance level of 5 %. This rather high expected effect of the early intervention treatment was chosen to ensure a certain level of practical relevance of the results. As, the aim was, if the early intervention reduced tail biting outbreaks, to recommend farmers to implement the early intervention strategy in their daily routines. Therefore, in order to get farmers to change management routines the effect must be of a certain magnitude to ensure relevance in practise.

Experimental herd

The third study was conducted in the same herd as study II and IV. Thus, pen design, genetics and management routines remained the same as in study II and IV including the daily provision of very fine chopped wheat straw.

Animals and housing

Study III included 1,804 undocked ear-tagged nursery pigs (6 to 30 kg) from three different farrowing batches. According to the herds' efficiency report, the lactation period was on average 28.4 days. At group mixing after weaning, pigs were sorted by size with 30 pigs per pen (SD 0.56; 0.35 m^2/pig). In total 60 pens were included in the study.

Experimental design

When one pig in a pen was observed with a tail wound (fresh or scabbed; See Table 3.2) or a tucked tail, one of four treatments were allocated to the pen; straw, haylage, rope or nothing (control pens) in a predetermined random order.

It was decided not to rely only on tail position (up or hanging), as the results from study II revealed that tails were also hanging in pens not close to an outbreak (Figure 4.2). Furthermore, as one direct observation of tail posture three times weekly was used to decide whether tail damaged pigs were present, it seemed too vague to only rely on tail position, as other elements beside tail damage influence tail posture, as discussed by Larsen et al (2017) and seen in Study II. A 'tucked tail' was included as intervention criteria even though the tail end was not visible, as an earlier study (Zonderland et al., 2008) had demonstrated a high correlation between tucked tails and tail damage (see Figure 3.6 for difference between hanging and tucked tail).

Study III was designed to compare the prevalence in tail biting outbreaks between pens with an early intervention and control pens. Hence, each intervention group was compared with the control group and the number of control pens was therefore twice the number of pens with an intervention to optimize sample size and increase statistical power.

Treatments – early intervention

In pens with straw treatment, the straw was chopped in a combine harvester and the straw length was longer (Figure 3.8) than the very finely chopped straw provided daily from weaning (Figure 3.9). Approximately 200 g of chopped wheat straw was provided once daily on the floor (Figure 3.10).

In pens with haylage, 650 g was provided once daily in a spherical cage with a diameter of 30 cm (https://heuballferkel.jimdo.com/) hanging in the middle of the pen above the solid floor (Figure 3.10). The spherical cage was placed at a height enabling pigs to pull haylage from the bottom. In the

Figure 3.8 200 g of regular standard chopped straw allocated in pens with straw treatment in study III and IV.

Figure 3.9 Very finely chopped straw provided daily throughout the study period irrespective of treatment group in study II, III and IV.

third group, sisal rope (diameter; 20 mm) with a 650-g apple tasting lick block was placed at the same location in the pen as the spherical cage with the lick block in the same level as the head of the pigs (www.likit.co.uk/treats-toys/horse-licks/). According to the manufacturer, the Likit™ block was composed of glucose syrup, dextrose, ground sunflower seed and blue-green algae extract. Rope was pulled through the block leaving 30 cm of rope lying on the floor. To keep the block in place, just above and below the block, a knot was made on the rope (Figure 3.10). Above each pen hung a coil of rope and every second day, if no rope was lying on the floor, new rope was pulled from the coil leaving 30 cm on the floor. In control pens no new enrichment was provided on the day, when the first damaged or tucked tail was observed.

Measurements

Tail posture and tail damage

Three times weekly from weaning and until a tail biting outbreak tail posture and tail damage were recorded on standing pigs from outside the pen according to Table 3.4. Before recording tail posture, the observer went into the pen, made every pig stand, walked outside the pen and carried out the recording.

Clinical examination of tails after intervention

From the day of the early intervention and until a tail biting outbreak, pigs were individually tail scored three times weekly in the same way as in study II (Table 3.2). A tail biting outbreak was, as in study II and IV, defined as four pigs with a tail wound (fresh or scabbed). Pens with a tail biting outbreak left the study, and additional enrichment was provided to stop the tail biting.

Table 3.4 Tail posture and tail damage.

Tail posture/ tail damage	Description
Tail posture	
Curly	Tail is up and curly
Hanging	Tail is down and hanging relaxed alongside the rear end of the pig
Tucked	Tail is down and pressed into the rear end of the pig
Hanging tails – tail condition[1]	
Intact tail	Hanging tail with no visible change in colour as a sign of a tail wound
Scabbed wound on tail end	The tail end is black and covered with a scabbed wound
Bleeding tails	
Bleeding wound	Tails with a fresh wound irrespective of tail posture

[1] Tail condition was only scored on hanging tails. It was not possible to score the tail condition (wound or not) on tucked tails from outside the pen.

Data management and statistical analysis

Statistical analyses were performed using SAS Enterprise Guide 7.1 (SAS Institute Inc., Cary, NC, USA) with significance level of $P < 0.05$ and tendency level of $P < 0.10$. The pen was the experimental unit (see argumentation under study II). An early intervention was applied in 44 pens. In the remaining 16 pens, at least four pigs (tail biting outbreak definition) had a damaged tail on the day when the first pig was observed with an injured tail from outside the pen. These pens were excluded, as it was too late for an early intervention with the applied criteria of a tail biting outbreak.

In study III data were analysed using the GLIMMIX procedure. In the model comparing the prevalence of tail biting outbreaks between the control treatment and each of the early intervention treatments (straw, haylage or rope), treatment and age at intervention were included as fixed effects and batch as a random term.

The effect of the percentage of hanging tails on tail damaged pigs recorded on the same day at the first five recording days after the early intervention day was analysed using GLIMMIX with repeated measurements at pen level. To ensure homogeneity of variance, the variable 'number of damaged tails' was square root transformed. Recording day after intervention and age at intervention were

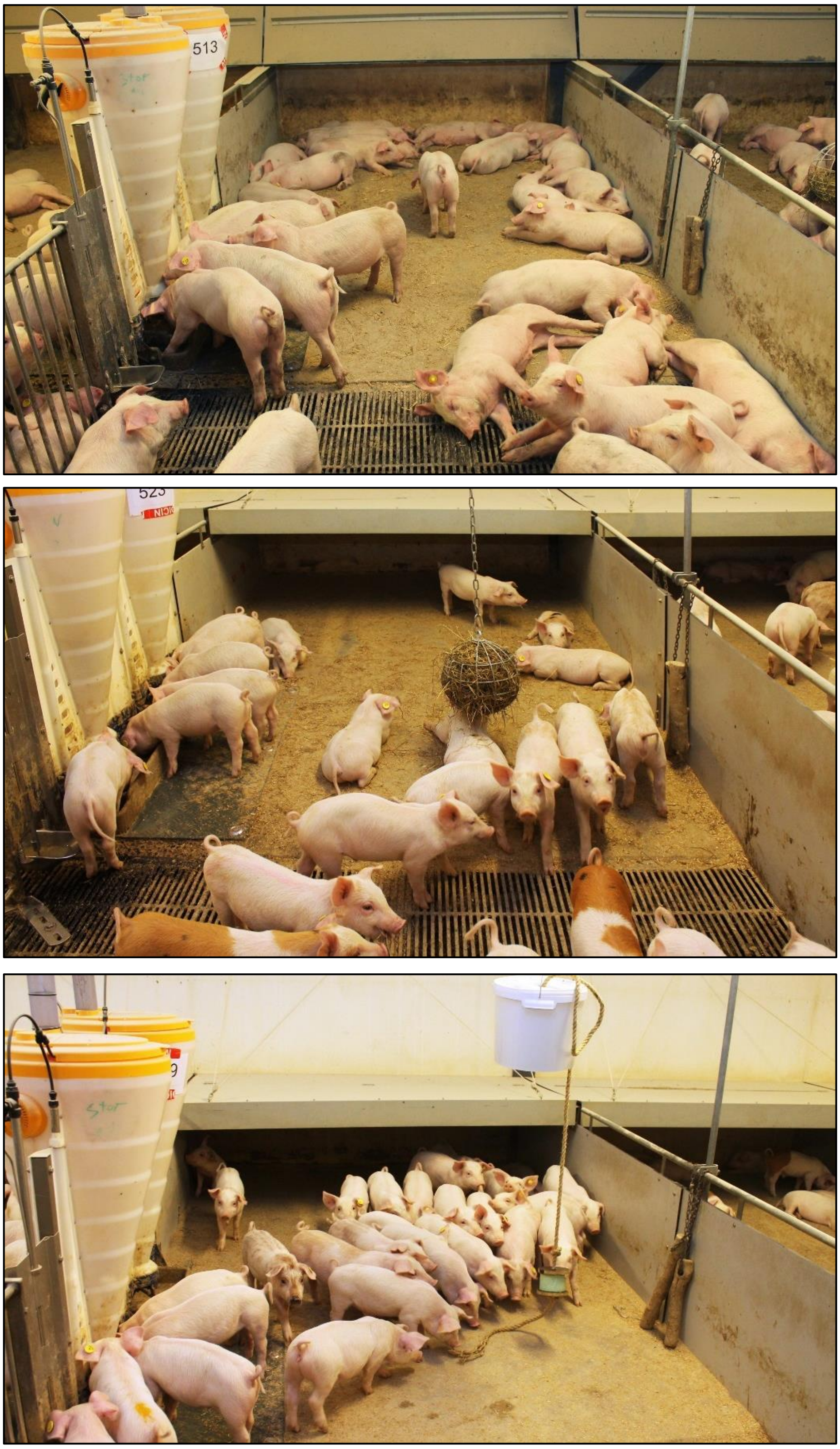

Figure 3.10 The top picture is from a pen with straw on the floor as an early intervention. The picture in the middle is from a pen with haylage and the bottom picture is from a pen with rope and lick block as early intervention.

included as systematic effects, whereas pen was included as a random effect. Data presenting the correlation between hanging tails and tail damage had the best fit to a curve based on a quadratic equation. The number of tail damaged pigs in pens with either 0, 10, 20, 30 or 40 % hanging tails was estimated. Results are presented as back-transformed least square means with 95 % confidence limits.

3.4 Study IV - Enrichment intervention in pens with tail biting outbreak (Paper IV)

The aim of study IV was to examine which enrichment materials (applicable at conventional piggeries) that most efficiently prevented an escalation in tail damaged pigs in pens with a tail biting outbreak.

Power calculation and sample size

The aim of study IV was to investigate the effect of three different enrichment treatments in pens with a tail biting outbreak. No power calculation was conducted to determine the number of pens in study IV. It was, however, decided to include three treatments resulting in at least 15 pens per treatment with a tail biting outbreak in 50 % of the pens as expected in study II. Compared to other enrichment studies including tail damage recording, this seemed a reasonable sample size (Van de Weerd et al., 2006; Zonderland et al., 2008; Larsen et al., 2017).

Animals and housing

As study IV was conducted on the same pigs used in study II, animals and pen design were identical (Section 3.3). In total 70 pens were included in study IV, as a tail biting outbreak occurred in 70 of the 74 pens included in study II.

Biters

If a pig was observed walking from one pig to another chewing/biting the tail so hard that the receiver screamed, reacted by suddenly moving away or turning against the biting pig, it was removed from the pen. Biters were identified during the daily health inspections by the stockperson or at the weekly tail scorings.

Enrichment treatments in pens with a tail biting outbreak

In pens with a tail biting outbreak, defined as four pigs with a tail wound irrespective of wound freshness, one of three enrichment treatments were provided in a predetermined random order: straw on the floor, hanging rope or a Bite-Rite.

In pens with straw treatment approximately 200 g of chopped wheat straw was provided once daily on the solid floor (Figure 3.8 and Figure 3.10). In rope treatment pens, sisal rope (diameter; 20 mm) was hanging down in the middle of the pen approximately 1 m from the solid floor (Figure 3.11). Rope was pulled from the coil hanging above the pen leaving roughly 30 cm of rope on the floor with a knot about 20 cm from the end of the rope. If rope was consumed the knot was untied and new rope

Figure 3.11 The top picture is from a pen provided with rope, and the bottom picture is from a pen provided with a Bite-Rite as an enrichment treatment in pens with a tail biting outbreak.

was pulled from the coil once daily. In the Bite-Rite (Ikadan Systems A/S, Ikast, Denmark, http://www.ikadan.dk/Default.aspx?ID=3195) treatment pens (Figure 3.11), the Bite-Rite hung in same location as the rope at a height ensuring the pigs had access to chew the plastic sticks when standing and sitting.

The enrichment treatment was deemed to have failed in preventing further tail damage ('an escalation in tail biting') if either of two criteria were met:

1) if four fresh tail wounds were observed on tail scoring days (day 7, 14, 21 etc.) or during daily pen inspection between recording days

2) if a biter was removed from the pen

Removing the biting pig was used as a criterion as this measure also reflected that the enrichment treatment did not serve the main purpose; to stop the tail biting. When the term 'an escalation in tail biting' is applied in the following, it refers to the sum of pens with removed biters and pens leaving the study due to an increase in tail damaged pigs (four fresh wounds).

Scoring of tail injuries and tail posture

After a tail biting outbreak, tail injuries and tail posture were recorded until the pen left the study according to the criteria described in the previous paragraph. Tails were scored once weekly on day 7, day 14, day 21 etc. in the same way as prior to the outbreak (Table 3.2). Tail posture was recorded three times weekly in the same way as described in study II.

Data management and statistical analysis

Statistical analyses were performed using SAS Enterprise Guide 7.1 (SAS Institute Inc., Cary, NC, USA) with significance level of $P < 0.05$ and tendency level of $P < 0.10$.

Of the 70 pens with a tail biting outbreak, nine pens were excluded from this part of the study leaving 61 pens for the statistical analysis (1933 pigs). The nine pens were excluded either because the outbreak occurred within the last week of the study (4 pens), or because a biter was removed from the pen on the day of the tail biting outbreak (5 pens). Pens with an outbreak within the last week of the study were excluded as the effect of the treatment could only be followed for a short period. Also, pens with a biter removed on the day of the tail biting outbreak were excluded, as removing the biting pig might influence the effect of the enrichment treatment. Included in the analysis were 22 pens with the straw treatment, 20 pens with the rope treatment and 19 pens with the Bite-Rite treatment.

The GLIMMIX procedure was used to analyse the effect of the enrichment treatment (straw, rope or Bite-Rite) at pen level (experimental unit) on a potential escalation in tail damaged pigs (binary variable). Treatment and days after weaning until outbreak were fitted as systematic effects and batch was a random effect in the model.

Before statistical analysis on tail damage severity the tail injuries were grouped according to severity and tail length, but irrespective of damage freshness (0=no tail damage, 1=tail injury present and full tail length (mild), 2= tail injury present and tail loss or swollen tail (moderate)). The effect of treatment on tail damage severity at pig level was also analysed using the GLIMMIX procedure. Days from weaning until treatment were included as a fixed effect and pen as random effect in the model.

Data regarding weight gain were analysed using the MIXED procedure with tail damage severity and weaning weight as fixed effects, and pen as random effect. Sex did not influence weight gain and was removed from the model. The effect of sex, on the probability of becoming a victim and tail damage severity was analysed using a χ^2-test.


513

4. Results

The main results from the four studies are presented in this section.

4.1 Study I – Tail damage prevalence in docked and undocked pigs (Paper I)

The objective of study I was to compare the prevalence of tail damaged pigs between docked and undocked pigs housed in a Danish piggery with a low prevalence of tail injuries among tail docked pigs. None of the tail docked pigs were recorded with a tail injury, whereas 220 of the undocked pigs (23 %) were scored with tail damage and 24 of the 220 bitten pigs (10.9 %) had to be removed to a hospital pen due to the severity of the tail damage. The 220 tail damaged pigs were distributed in 32 different pens (68 % of the pens with undocked pigs), and half of the tail injuries were recorded within 37 days after weaning. Tail injuries scored based on the criteria listed in Table 3.1 are presented in Table 4.1. In Table 4.1 the recorded injuries are sorted according to tail length, the type of injury including wound freshness and last if the tail was swollen as an indication of infection. Most frequently pigs with an injured tail were recorded with a scabbed wound and a part of the tail missing. Overall, more castrated males were scored with tail damage than gilts (124 vs 82, F = 13.0, P < 0.001).

Table 4.1 Tail damage recordings (n = 257) and distribution (%) among undocked pigs with a clinical injured tail.

Tail score	n[1]	%
Intact tail, red/clean and/or minor scratches	1	0.4
Intact tail, fresh wound and swollen tail	1	0.4
Part missing and fresh wound	3	1.2
Part missing and scabbed wound	241	93.8
Part missing, scabbed wound and swollen tail	11	4.3

[1] 257 clinical injured tails were recorded on 220 different pigs.

Effect of growth stage on tail damaged pigs

Growth stage influenced the prevalence of tail damaged pigs (F = 21.9, P < 0.001). More pigs weighing 30-60 kg had tail damage than pigs weighing 7-30 kg and 60-90 kg (P < 0.05), and fewer pigs weighing 60-90 kg had tail damage than pigs weighing 7-30 kg (P < 0.05, Table 4.2). Furthermore, more pens were observed with tail damaged pigs from 30-60 kg than from 7-30 kg and 60-90 kg (P < 0.05, Table 4.2).

Table 4.2 Percentage of undocked tail damaged pigs and pens with tail injured undocked pigs in three growth stages: 7-30 kg, 30-60 kg, 60-90 kg.

	Growth stage			
	7-30 kg	30-60 kg	60-90 kg	P-value
Tail injuries pig level				
Pigs (n)	959	933	919	
Tail damage per pen (%) [1]	5.0[a] (4.0-6.1)	6.6[b] (5.3-8.2)	1.4[c] (0.91-2.2)	< 0.001
Tail injuries pen level				
Pens (n)	47	47	47	
Pens with tail damaged pigs (%) [1]	13.0[a] (8.2-19.9)	34.3[b] (24.3-46.1)	12.8[a] (7.3-21.6)	< 0.001

[1] Different superscripts a and b within a row indicate a significant difference of $P < 0.05$, ( ) = 95 % confidence limits.

Abattoir tail lesion remarks

At the abattoir, more pigs with undocked tails (17 pigs, 2.0 %) than tail docked pigs (3 pigs, 0.32 %) received a tail lesion remark ($\chi^2_{(1,\ N=1786)} = 11.2$, $P < 0.001$). The percentage of undocked pigs getting a tail lesion remark at the abattoir was markedly lower than the percentage of tail injured pigs recorded on farm for these pigs.

4.2 Study II – Behavioural changes before a tail biting outbreak (Paper II)

The objective of study II was to investigate if the behaviour of the pigs and tail posture changed at pen level prior to a tail biting outbreak.

Tail damage prevalence and tail biting outbreaks

A tail biting outbreak occurred in 70 of the 74 experimental pens. Tail biting outbreaks developed on average 26.6 days after weaning (*SD* 11.0, *Range* 9-49 days, Figure 4.1), and on the day of the outbreak 7.6 pigs/pen (*SD* 4.3, *Range* 4-27 pigs/pen) had an injured tail.

The distribution of tail injuries at weaning and on the day of the tail biting outbreak (day 0) is listed in Table 4.3. At weaning 5.7 % of the pigs were scored with a damaged tail, whereas on the tail biting outbreak day 23.8 % were scored with tail damage. All the injured tails at weaning were still full length, as were most of the tails on the day of the outbreak in the weaner period (98.2 %).

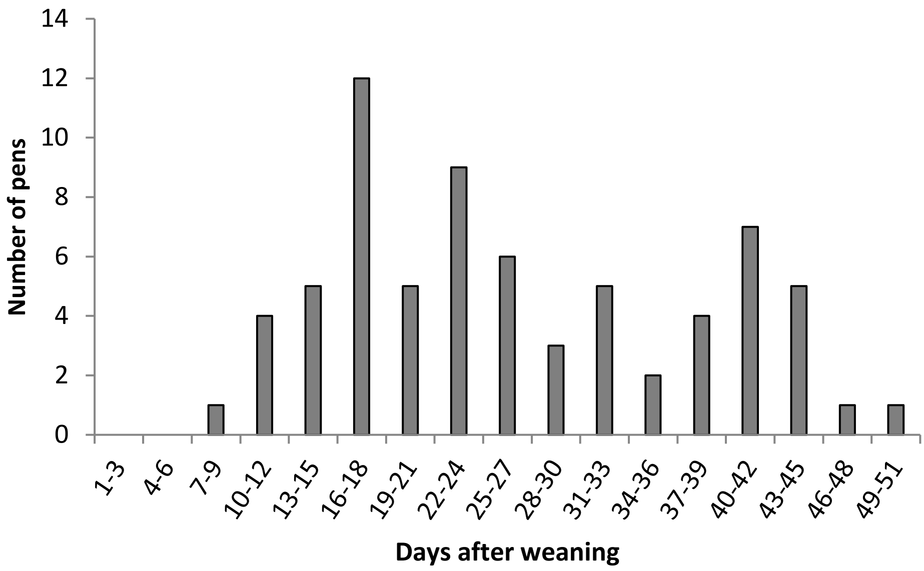

Figure 4.1 Distribution of tail biting outbreaks (n = 70) at pen level according to days after weaning.

Table 4.3 Frequency of tail injuries (n) and distribution (%), broken down to injuries on intact tails, and injuries when part of the tail was missing at weaning and on the tail biting outbreak day (day 0).

Tail score	At weaning (Farrowing stable)		Tail biting outbreak (Day 0)	
	n	%	n	%
No tail injury	2131	94.3	1706	76.2
Intact tail length and...				
Scratches, intact scab	69	3.1	15	0.7
Scratches, scab not intact	0	0	17	0.8
Wound, intact scab	57	2.5	311	13.9
Wound, scab not intact	0	0	90	4.0
Fresh wound, not bleeding	0	0	21	0.9
Fresh wound, bleeding	2	0.1	38	1.7
Outer part of tail was missing and…				
Wound, intact scab	0	0	18	0.8
Wound, scab not intact	0	0	7	0.3
Fresh wound, not bleeding	0	0	5	0.2
Fresh wound, bleeding	0	0	6	0.3
Intact, outer part of tail will fall off	0	0	5	0.2
Total [1]	2259	100	2239	100

[1] Some pigs were moved to hospital pens or died between the tail scoring at weaning and day 0. In total 42 pigs were not tail scored at weaning.

Behavioural changes prior to an outbreak (video)

Results obtained from video recordings are presented in Figure 4.2. The results demonstrated a higher number of tails down (sum of hanging and tucked) in pens with an upcoming tail biting outbreak (T-pens) than in control pens (C-pens) on each recording day ($P < 0.001$). However, no difference was

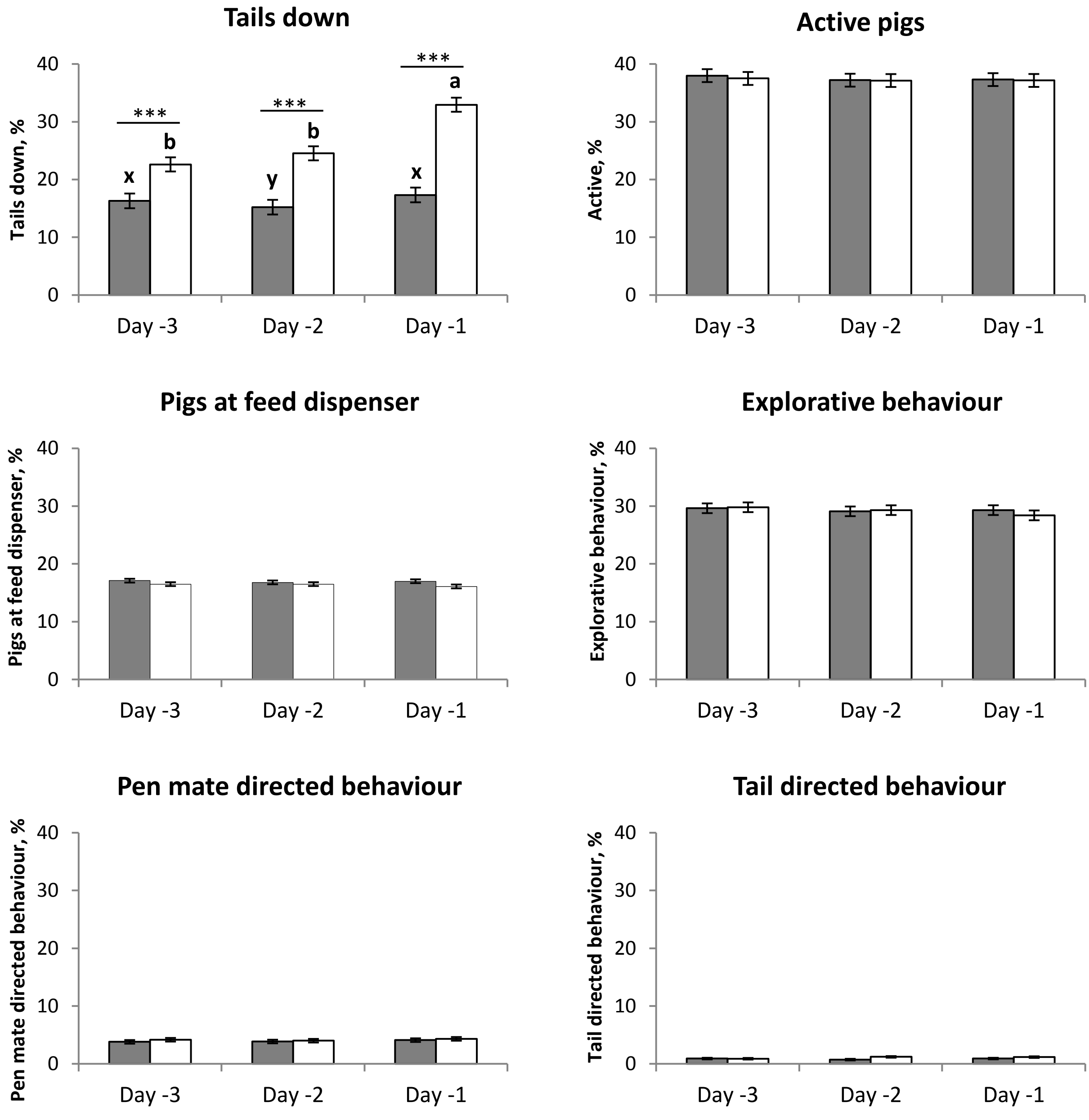

Figure 4.2 Percentage of tails down, active pigs, pigs at the feed dispenser, explorative behaviour, pen-mate directed behaviour and tail directed behaviour in C-pens (■) and T- pens (□) on Day -3, Day -2 and Day -1 before a tail biting outbreak (14 half-hourly scan samples 0800–1100 h and 1700–2000 h on video). Data is presented as LSmeans (± SE). Different superscript a and b indicate a significant difference of $P < 0.05$ between days which do not share a letter in T-pens. X and y indicate a significant difference of $P < 0.05$ between days which do not share a letter in C-pens. *** indicate a significant difference of $P < 0.001$ within day between C-pens and T-pens.

observed between T- and C-pens in terms of activity, pigs at the feeder, pigs performing explorative behaviour or pigs nosing the body of pen mates, but there was a non-significant tendency of more tail directed behaviour in T-pens ($P = 0.06$).

Changes in tail posture to an outbreak (direct observation)

Direct observations of tail posture in upcoming pens with a tail biting outbreak showed a higher percentage of hanging or tucked tails on the day of the tail biting outbreak compared to on the recording days prior to the outbreak ($P < 0.05$, Figure 4.3).

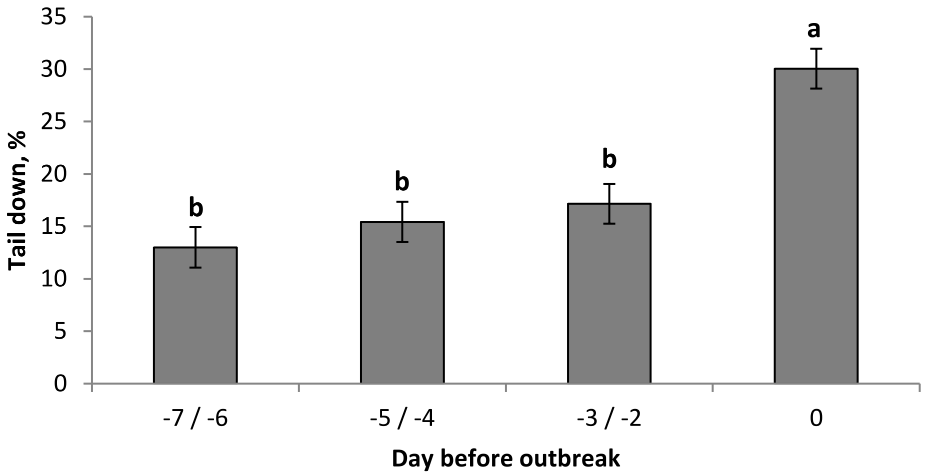

Figure 4.3 Percentage of tails down based on direct observation of tail posture on day -7/-6, 5/-4, -3/-2 and 0 in pens with a tail biting outbreak on day 0. Data is presented as LSmeans (± SE). Different superscript a and b indicate significance difference of $P < 0.05$ between bars which do not share a letter.

Tail posture recorded on video and number of tail damaged pigs

On the day prior to the outbreak (day -1) more tails were hanging in pens with 6-8 or >8 tail damaged pigs, than in pens with 4-5 tail damaged pigs on day 0 ($P < 0.001$, Figure 4.4). No difference between groups (categories of tail damaged pigs on day 0) was observed on day -3 and -2. Additionally, in pens with at least six tail damaged pigs on day 0, a higher number of tails were found to be hanging on day -1 than on day -2 and day -3 ($P < 0.001$, Figure 4.4).

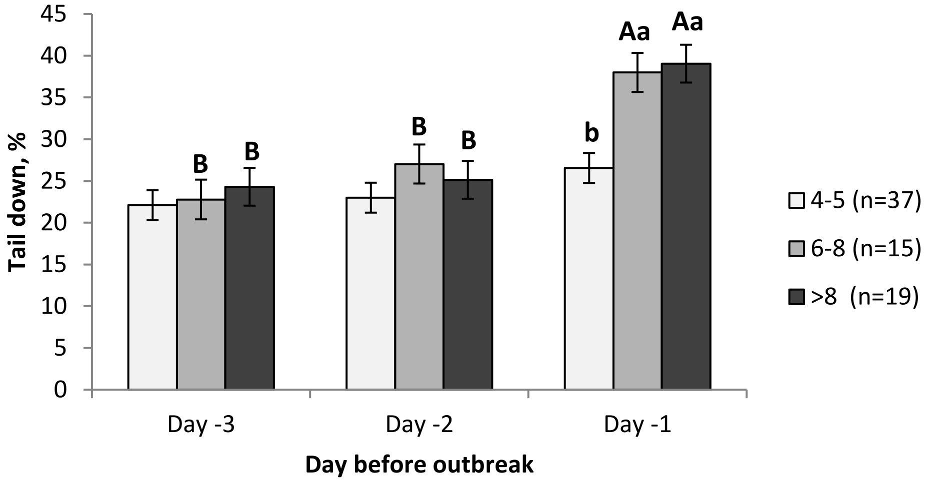

Figure 4.4 Percentage of tails down at the pen level on day -3, -2 and -1 according to the number of tail damaged pigs on day 0 (4-5, 6-8 or > 8 tail damaged pigs). Data is presented as LSmeans (± SE). Different superscript letters a and b indicate significant difference of $P < 0.001$ between pens within day. Different capital letters A and B indicate significant difference between days within group of $P < 0.001$.

Tail damage - litter origin and weaning weight

Pigs originated from 222 different litters and pigs scored with a scratch or a wound originated from 88 different litters (128 pigs, *Range* 1-4 pigs per litter). The risk of getting a tail injury in the weaner period until a tail biting outbreak was not correlated with litter origin ($F = 0.87$, $P = 0.91$). At weaning, pigs were sorted by size at the pen level, and the average pen level weaning weight did not influence when a tail biting outbreak occurred after weaning ($R = 0.03$, $N = 70$, $P = 0.80$).

4.3 Study III – Early intervention and prevalence of tail biting outbreaks (Paper III)

The objective of study III was to investigate if allocating extra enrichment when the first tail damaged pig was observed reduced the prevalence of tail biting outbreaks. In total, an early intervention was provided in 44 of the 60 pens, as 16 pens had to be excluded. These pens were excluded either because a tail biting outbreak already was present on the day of the intervention (14 pens), or because no tail injured pigs were observed at all during the study period (two pens). The first tail damaged pig was observed on mean 13 days (*SD* 10.2, *Range* 2-42 days, Figure 4.5) after weaning, and on the day of the early intervention a mean of 1.7 pigs per pen (*SD* 0.74, *Range* 1-3 pigs) had a fresh or scabbed tail wound.

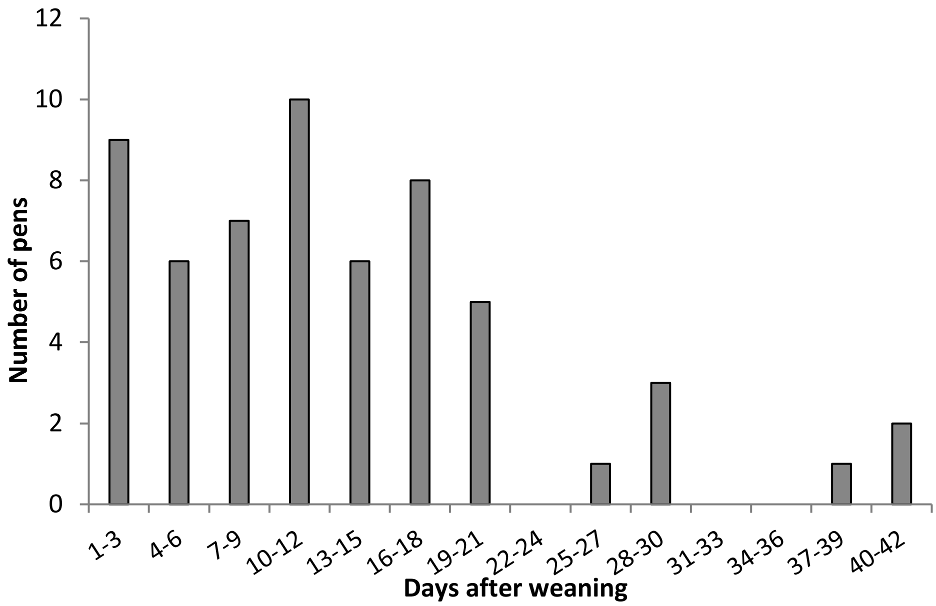

Figure 4.5 Distribution pens according to days after weaning when the first pig was observed with a tail injury throughout the experimental period (n = 58).

During the experiment, no pigs had to be moved to a hospital pen due to tail damage. In pens with a tail biting outbreak, the biting behaviour ceased either by giving extra enrichment or by removing the biting pig. In the course of the study one biter was removed from a control pen, ten days after the first pig was observed with tail damage. No biters were removed from pens with an early intervention.

Effect of early intervention

A tail biting outbreak (four pigs with a tail wound - fresh or scabbed) developed in one pen with haylage, two pens with rope and two pens with straw (Table 4.4). The risk of a tail biting outbreak was lower in pens with haylage and straw than in control pens without an early intervention (Table 4.4). There was a non-significant tendency of fewer tail biting outbreaks in pens with rope than in control pens.

A tail biting outbreak occurred in 68 % of the control pens (13 pens out of 19 pens) and in 42 % of the control pens (8 pens out of 19 pens) the tail biting outbreak occurred within 2-5 days after the day when the first tail damaged pig was observed (data is presented in Paper III).

Table 4.4 The number of pens with an early intervention, the number of pens with a tail biting outbreak and the average number of tail damaged pigs per pen on the early intervention day (day 0) and on the day of the tail biting outbreak (SE).

	Intervention				*P*-value		
	Control	Straw	Haylage	Rope	C x S	C x H	C x R
Number of pens, n	19	10	8	7	-	-	-
Tail damaged pigs, day 0	1.7 (0.73)	1.5 (0.71)	1.4 (0.52)	2.1 (0.9)	0.22	0.45	0.46
Pens with tail biting outbreak, n	13	2	1	2	-	-	-
Pens with tail biting outbreak, % of pens[1]	73 (18.3)	15 (14.6)	8.9 (10.9)	28 (23.8)	< 0.05	< 0.05	0.08
Tail damaged pigs per pen on the day of the outbreak, n	7.4 (6.0)	15.5 (14.9)	4	4.5 (0.7)	-	-	-

[1] The overall F-test (F = 3.48) of differences between interventions had a P-value = 0.03. Data is presented as LSmeans.

Direct observation of tail posture and number of tail damaged pigs

Results showed that the number of tail damaged pigs increased with percentage of hanging tails (F = 7.97, P < 0.01, Figure 4.6) when compared on the five subsequent recording days after the early intervention. More tails were damaged when 20 % or more of the tails were hanging as compared to when 10 % or less tails were hanging (P < 0.001).

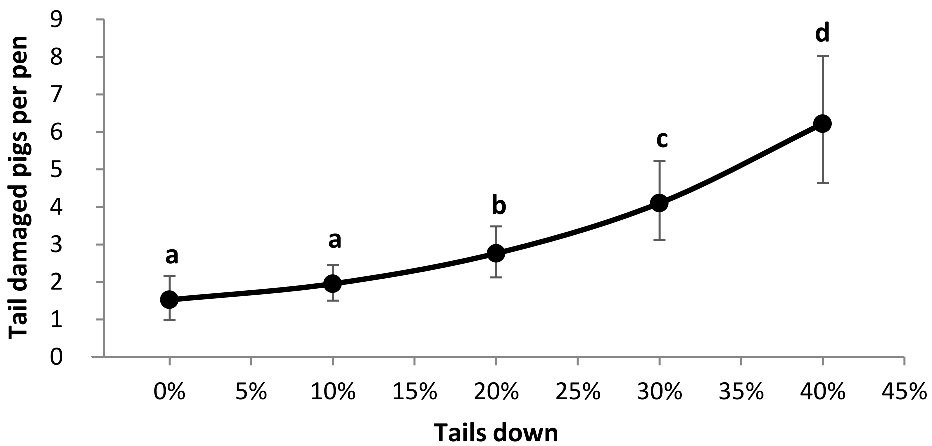

Figure 4.6 Plot of the percentage of tails down (back-transformed least square means and 95 % confidence limits) against the average number of tail damaged pigs per pen within the first ten days after the early intervention (n = 255). Different superscripts indicate significant difference of P < 0.001.

4.4 Study IV - Enrichment treatment in pens with a tail biting outbreak (Paper IV)

The effect of three different enrichment treatments on tail damage in pens with an outbreak were examined in 61 pens (22 pens with straw, 20 pens with rope and 19 pens with Bite-Rite).

There was no difference in number of tail damaged pigs per pen between treatments on day 0 (F = 0.19, P = 0.83), and the number of tail damaged pigs on the day of the tail biting outbreak did not influence the risk of an escalation in tail damage (F = 0.10, P = 0.76). In total 843 pigs (44 %) of the 1933 pigs included in this part of the study were recorded with a tail injury. Of the tail damaged pigs, 35 % had tail loss (15 % of the pigs). The remaining pigs with a tail injury had a full-length tail.

Effect of enrichment treatment

There were more pens with at least four fresh tail wounds after the tail biting outbreak in the Bite-Rite group than in the group provided with straw (P < 0.05, Figure 4.7). There was no difference in number of pens experiencing an escalation in tail biting between rope and Bite-Rite, and there was no difference between rope and straw treatment in the escalation of tail biting.

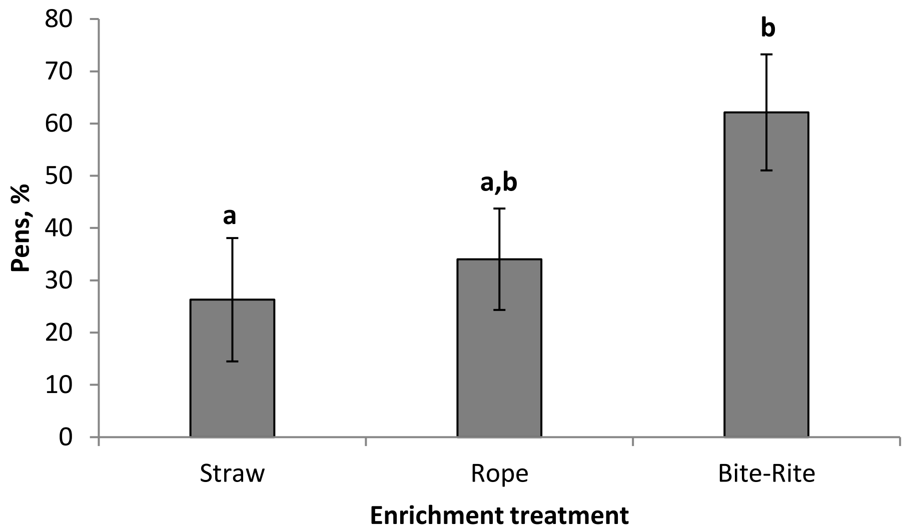

Figure 4.7 Percentage of pens with an escalation in tail biting presented as LSmeans (± SE) according to treatment. Different superscript a and b indicate significant difference of P < 0.05 between treatments not sharing a letter.

In total fewer pigs received a tail damage in pens provided with straw (16.7 %) than in pens provided with a Bite-Rite (25.6 %, t = 3.81, P < 0.001) or rope (22.8 %, t = 2.69, P < 0.01). There was no difference in the number of tail damaged pigs between rope and Bite-Rite.

Tail damage - weight gain and sex

Pigs scored with mild (intact tail length) or moderate (tail loss) tail injury in pens with a tail biting outbreak had a higher weight gain, 23.5 kg and 24.2 kg, respectively, than pigs without tail damage (22.8 kg, $t = 3.15$, $P < 0.01$). In addition, pigs with a moderate tail damage had a higher weight gain than pigs with a mild tail damage ($t = 2.07$, $P < 0.05$). Sex did not influence the probability of becoming a tail biting victim ($\chi^2_{(1, N = 1947)} = 1.10$, $P = 0.29$) or influenced the severity of the tail injury ($\chi^2_{(2, N = 826)} = 0.10$, $P = 0.95$).

5. Discussion

The overall aim of the thesis was to reduce the need for tail docking in conventional pig production systems. This was obtained by investigating the consequences of not tail docking in current production systems, and by investigating if pens with a tail biting outbreak can be identified prior to the outbreak and if enrichment materials applicable under conventional conditions could stop the biting. Before discussing the results, the suitability along with the advantages and disadvantages of the chosen data collection methods will be discussed to support the validity of the obtained results.

5.1 Data collection methods, treatments and data analyses

One of the challenges with the experimental setup was that the prevalence of tail biting (and tail damage) could not be determined beforehand, nor when it would occur. Also, a general definition of a tail biting outbreak did not exist and had to be defined. Furthermore, to mirror conventional pig production, the studies were conducted in conventional piggeries which added to the overall complexity. These are some of the challenges that will be discussed in this section.

Conducting experiments at conventional piggeries

The studies included in this thesis were conducted at commercial piggeries. The housing environment could therefore not be controlled and monitored to the same extent as if the experiments had been conducted at a research facility. Thus, some risk factors occurring at a commercial piggery, not occurring at a research facility, might have triggered the tail biting. This could, for instance be, a temporary break down in the feeding system or sudden change in climate. However, by using commercial piggeries a level of practical relevance was guaranteed which would not be possible to attain in a research facility.

Choice of piggeries for experiments

As tail biting risk factors differ between production systems (Section 2.2), the allocated interventions in study III and IV might not have had the same effect in other piggeries. It would, therefore, have been preferable to include more piggeries, but due to restricted finances this was not possible. However, applying only one piggery or research facility to examine the effect of enrichment on tail damage has been used in previous studies (Zonderland et al., 2008; Telkanranta et al., 2014a; Ursinus et al., 2014b; Larsen et al., 2017). Similarly, more piggeries would have been preferable to establish the prevalence of tail injuries in the kind of conventional piggery applied in Study I.

Including more piggeries in Study I, would have resulted in a more robust validation of the consequences of not tail docking in current conventional production systems. However, since the study was conducted in a piggery, which prejudged was assessed to be a low-risk tail biting conventional piggery, the prevalence of tail damage among the undocked pigs was expected to be lower than if the study had been conducted in a piggery with a higher risk of tail biting. This could for example be a herd with less accessible enrichment, higher stocking density in the weaning period, no solid floor in the lying area or lower health status (Hunter et al., 2001; Scollo et al., 2016).

In retrospect, the piggery included in study I was a 'high-risk' tail biting piggery, when pigs had long tails. Perhaps, the prevalence of tail injuries among undocked pigs could have been reduced by providing more enrichment on a daily basis, ensuring better access to feed, reducing stocking density and improving the overall health. Another approach, which may have reduced the overall prevalence of tail injuries, could have been to improve management routines and reacting to early signs of tail biting. If the tail injuries were detected in the early stages using changes in tail posture, as demonstrated in study II and extra enrichment were provided at this point (study III), it might have reduced the number of tail damaged pigs and the severity of tail damage.

Prior to the data collection in study I, a systematic assessment of tail biting risk factors could have been carried out using the husbandry advisory tool (HAT) presented in Taylor et al. (2012). The risk factors included in the HAT were organised in eight categories (atmosphere and environment, enrichment, feed/drink, health, within group indicators (varying tail lengths, agitation etc.), mixing and moving, pen space and tail biting history). Even though the piggery in study I was not assessed systematically according to HAT, atmosphere and environment, access to enrichment, feeding and drinking, health, pen space and tail biting history were included in the assessment of the piggery. The piggery in study I had a low prevalence of tail biting remarks at the abattoir, provided straw daily, had a low stocking density during rearing, fed pigs according to Danish recommendations, had a very low tail damage prevalence among tail docked pigs and the ventilation system was checked and adjusted before study start. Based on these elements the experimental piggery was considered a low-risk tail biting piggery compared to standard conventional piggeries in Denmark and likely also compared to other piggeries across Europe. However, if HAT had been used to rank the farm, it would have made it comparable with the piggeries included in Taylor et al. (2012). Another possibility to evaluate tail biting risk factors systematically is with the SchwIP-tool (Dippel, 2018).

It could be that the feeding method at the piggery in study I with 6-7 pigs per eating space (three eating spaces per pen) and ad libitum access to feed increased the risk of tail biting compared to a system with fewer or one pigs per eating space. Several pigs per eating space may cause restricted access to feed, especially in certain periods of the day, where pigs are highly motivated to eat, as discussed by Moinard et al. (2003). An epidemiological study reported that feed level (restricted, to appetite or *ad libitum*) did not affect tail damage, whereas double or multi-space feeders reduced tail damage more efficiently than floor feeding, trough feeding or single space feeders (Hunter et al., 2001). Another epidemiological study categorising farms with tail biting challenges, as farms with at least one tail damaged pig within the last six months reported an increased risk of tail biting if there were five or more pigs per feeder space (Moinard et al., 2003). Also, Moinard et al. (2003) reported that farms with tail damaged pigs more often had liquid feeding in a trough. In a Finnish survey, farmers reported that there was an increased risk of tail biting if there were not enough feeding spaces (enough feeding space at the trough or enough feeding places at the feeder) (Valros et al., 2016).

A study reported that 30 % of the tail biting occurred at the feeder (1.7 pigs per eating space), whereas 48 % of the tail biting occurred on lying pigs in pens with tail damaged pigs (Sutherland et al., 2009). Unfortunately, tail biting behaviour was not defined in the publication. It is therefore not possible to determine whether the recorded tail directed behaviour in Sutherland et al. (2009) only included actual tail biting with a sudden reaction of the receiver or if it also included tail interest and tail-in-mouth. In a sub study, including 24 of the pens from study II, 39 % of the tail directed behaviour performed by the biter on the day before a tail biting outbreak, was observed when the targeted pig was standing at the feeder (5.2 pigs per eating space) (Spooner, 2016). In addition, 50 % of the tail directed behaviour was observed in the free space of the pen (not at a resource). In the sub study, of the tail directed behaviour recorded at the feeder, the performing pig only got access to the feeder in 4.3 % of the cases. In 92 % of the incidences access to the feeder remained the same after tail directed behaviour or the performing pig did not attempt to get access. At the remaining incidences (3.7 %) the victim moved away, but the feeder became blocked by another pen mate. Spooner (2016) suggested that since biting pigs only in few cases got access or attempted to get access to the feeder; it could be that feeding pigs are just easy tail biting victims and the biting at the feeder may not be due to feeding frustration. The findings by Sutherland et al. (2009) support this theory, as the same level of tail biting at the feeder (if tail biting corresponds to all tail directed behaviour) were reported with less than half the pigs per feeder space.

The study by Spooner (2016) cannot determine if several pigs per eating space increase the risk of tail biting, and frustration may have triggered the tail biting observed on feeding pigs. However, the study indicated that the tail directed behaviour at the feeder only occasionally was followed by a situation where the biting pig accessed the feeder. Thus, more research is needed to establish, at what level more pigs per feeding space increase the risk of tail damage. However, when estimating the effect of eating space, the influence of feed (meal vs pelleted), feed energy level, feed content, degree of grinding and feeder design should also be taken into consideration (Maselyne et al., 2015).

Tail biting studies – a challenge

Tail biting studies are often difficult to plan, control and conduct, because of the tail biting behaviour's sporadic occurrence (D'Eath et al., 2014). However, a way to deal with this challenge is to conduct large studies with many repetitions.

One of the aims of the project was to investigate if behavioural changes occurred prior to a tail biting outbreak (study II). Therefore, to test this hypothesis some tail biting was desired, but control pens without tail biting outbreaks were also needed. By the end of the study, with the applied threshold of a tail biting outbreak and housing environment, a tail biting outbreak occurred in most pens. To answer the hypothesis, it was therefore necessary to include pens that would get a tail biting outbreak later in the study period as control pens to pens with a tail biting outbreak at the beginning of the weaner period. Additionally, since tail biting outbreaks occurred in more than half the pens within a room, some pens were used as control pens more than once. It would have been preferable if a pen had only been used as a control pen once, but this would have decreased the sample size considerably.

Another challenge was to determine when changes in behaviour was expected to occur prior to a tail biting outbreak. In a pilot study, selected behaviours were recorded between day -13 and day -1 prior to an outbreak. By visually inspecting pilot study graphs, it became evident that changes in behaviour (if any) would likely occur within the last three days prior to the outbreak (Appendix Figure A.1) with the used threshold of a tail biting outbreak. Based on these findings, it was also decided to apply pens at least seven days away from an outbreak as control pens.

In the planning of study II, the decision was made that the behavioural changes to look for should be such that the indicator/indicators could subsequently be implemented in daily management routines in piggeries or in a future visual surveillance software. This decision might have caused that certain minor and perhaps critical behavioural indicators were missed.

The project also aimed to investigate if early intervention could reduce the risk of tail biting outbreaks (study III). Results and experience obtained from study II showed that an increase in tails down was an early warning sign of a tail biting outbreak. However, results also demonstrated that tails were hanging in control pens at least seven days away from an outbreak. It was therefore decided in study

III to combine hanging tails with inspecting the handing tails for tail damage to determine the onset of early intervention.

Based on experiences from study II, it was expected that by recording tail damage and tail posture from outside the pen three times weekly, early signs of an upcoming tail biting outbreak could be identified. However, by using this method, the achieved sample size in study III ended up being smaller than planned. Since, in 23 % of the pens on the day when the threshold of early intervention was reached, a tail biting outbreak was already ongoing (four pigs with a tail wound). Thus, in these pens it was too late to test the effect of an early intervention and the sample size became smaller than planned. This also suggest that the rate of escalation in tail biting differs between pens, and that three weekly tail inspections are not always sufficient to detect the early stages of tail biting.

Defining a tail biting outbreak

A definition of a tail biting outbreak was needed to carry out study II-IV. When reviewing the scientific literature, it became evident that the definition of a tail biting outbreak varies between studies as discussed in Section 2.3.

In study II-IV all wounds irrespective of freshness were included to define pens with a tail biting outbreak. On the contrary some previous studies have defined an outbreak only based on wound freshness (see Section 2.3). Using only fresh bleeding wounds to define a tail biting outbreak would exclude scabbed wounds from being counted. Excluding scabbed wounds from the definition would likely have reduced the prevalence or postponed the day of the outbreaks in study II, as only 44 (8.8 %) of the 501 pigs with a wound on day 0 (Table 4.3) had a bleeding wound. These 44 pigs were distributed in 18 of the 70 pens with a tail biting outbreak (data not shown). If the criteria of a tail biting outbreak had been the sum of 'fresh wounds not bleeding' and 'bleeding wounds', then 70 pigs (Table 4.3) distributed in 24 pens (data not shown) had fulfilled the tail biting outbreak criteria. These differences in tail biting outbreak definitions likely influence the outcome of tail biting studies, as tail biting quickly can develop within a group (Section 2.1). It can furthermore be speculated, if the effect of an intervention depends on for how long the behaviour has been going on, and if some pigs gets stimulated to continue biting by the taste of blood (Fraser, 1987; McIntyre and Edwards, 2002).

If the presence of a fresh wound is essential to determine if the tail biting will escalate further, then the interventions tested in study IV should have been distributed differently. Even though, no difference between treatments in number of tail damaged pigs on the day of the outbreak, there were numeric more pens with fresh wounds (data not shown) in the rope treatment (12 pens; range 1 to 17 pigs with fresh wounds per pen) compared to the straw (7 pens; 1 to 3 pigs with fresh wounds per pen) and Bite-Rite treatment (6 pens, range 1 to 8 pigs with fresh wounds per pen). However, in study IV no difference was reported between the rope and straw treatment in pens with an escalation in tail damaged pigs. This could indicate that the wound freshness is not as an important indicator, as the total sum of tail damaged pigs. Another explanation could be that wound freshness is essential, and that rope was more effective than a small amount of straw, as the tail biting was more pronounced (more fresh wounds) in pens provided with a rope than in pens provided with straw on the day of the outbreak. Yet again, perhaps neither wound freshness nor the total number of tail damaged is the critical factor, when the effect of different enrichment on tail damaged pigs is measured. It might be that the specific stressor triggering the tail biting (see Section 2.2), is the factor determining the effect of the enrichment intervention.

Altogether, it must be assumed that different tail biting outbreak definitions across studies likely influence the outcome of both preventive and intervention treatments, especially if a solitary tail damaged pig can occur without a further increase in tail injured pigs as indicated in study III. However, since at least four pigs had a tail wound in study II-IV, it is likely that the biting would have continued if an intervention was not conducted, also based on the tail biting outbreak definitions used in previous studies (Section 2.3).

It can be discussed, if the tail biting outbreak was identified in the early stages with the used definition of four tail wounds (either scabbed or fresh) in a pen with 31 pigs. However, with this definition, 98.2 % of the pigs had a full-length tail on the day of the outbreak, even though in some pens, many of the pigs had a tail injury on the day of the outbreak. If the threshold of a tail biting outbreak had been less than four pigs, fewer pigs might have experienced a tail loss, if there is a correlation between numbers of tail damaged pigs and tail loss with the used recording method on the day of the outbreak. In the present study pigs suffering from losing the outer part of the tail on the day of the outbreak were distributed in 11 pens (one or two pigs per pen) with a total of 4 to 6 tail wounds on the day of the outbreak (data not shown). Tails were scored three times weekly, but even though the stockperson did not observe tail biting outbreaks between recording days, the threshold with four pigs might have been exceeded on the day between recording days. Scoring tails daily would probably have reduced the number of pigs with tail damage on the day of the outbreak and perhaps pigs suffering from tail loss.

Criteria applied at tail scoring

A simpler tail scoring principle was applied in study I than in the other studies. Study I was planned and initiated before the pilot study in study II, and the tail scoring system in study I was therefore based on previous studies (Kritas and Morrison, 2004; O'Driscoll et al., 2013).

The tail scoring system applied in studies II - IV was prepared based on a pilot study and previous published studies mentioned just above. At tail scoring, four elements were evaluated; tail lesion size, wound freshness, tail length and wound infection. Using these four criteria together gave information regarding the severity and freshness of the tail injuries. The more detailed scoring system used in study II-IV improved the likelihood of objective scoring since the observer did not have to combine the four elements into one score. The detailed scoring system takes longer to learn and apply, but it is assumed to increase inter-observer reliability and likely also intra-observer reliability, because each criterion is assessed separately. To improve inter-observer reliability, besides evaluating the same tail injuries, in the beginning of the study, a one-page sheet with pictures of each score was used (see Appendix).

Choice of enrichment materials

The chosen enrichment materials for study III and IV aimed at improving the welfare of the animals by stimulating exploratory behaviour, and thereby reducing tail biting and consequently leading to fewer tail damaged pigs. As mentioned in Section 2.7, especially straw has been reported to reduce the risk of tail biting outbreaks. However, in pens with slatted flooring and vacuum based slurry systems only a limited amount of straw can be handled (D'Eath et al., 2014). In systems without solid floor other enrichment materials are needed, as providing straw will result in a major waste to the slurry system (D'Eath et al., 2014). The chosen enrichment materials and amounts for study III and IV were selected, as they possessed properties to be implemented in practice if they could prevent a further escalation in tail damaged pigs.

A general challenge in studies testing the effect of different treatments is the lack of proper blinding of treatment groups. Lack of blinding can lead to an overestimation or underestimation of treatment effect, especially if the outcome is based on a subjective evaluation (Schulz and Grimes, 2002; Tuyttens et al., 2014). To minimise this bias, trained observers did all the tail recordings, and the outcome of the studies (tail damage and tail biting outbreaks) was determined based on individual tail scoring using a picture based sheet (Appendix).

Very little research has been conducted investigating the effect of different enrichment treatments in pens with tail biting outbreaks, as discussed in Section 2.8. However, even a small amount of straw seemed promising in the study by Zonderland et al. (2008). A small amount of straw will likely be practically manageable in systems with partly solid flooring. For pens without solid floor, rope could be a possible intervention to reduce tail biting, as rope is destructible and manipulable, which are essential features to keep pigs interested (Studnitz et al., 2007). However, no previous studies have investigated the effect of providing rope on tail damaged pigs in pens with a tail biting outbreak. The third chosen intervention strategy in study IV was a Bite-Rite. Previous studies reported that pigs engaged less with a Bite-Rite compared to other materials (Van de Weerd et al., 2006), but the effect of a Bite-Rite on tail damage in pens with an outbreak had not previously been investigated and the Bite-Rite is an object often preferred by pig producers. However, as the plastic sticks on the Bite-Rite are less changeable and rootable (not lying on the floor) compared to straw and a rope-end, it was anticipated to have less of an effect on tail biting.

Beside rope and straw, it was decided to include haylage provided in an elevated spherical metal cage as an early intervention treatment in study III. Providing the material in an elevated container likely increases the presence of the material as pigs must extract the material from the container before rooting it on the floor. Since the material, after being allocated, only can be accessed by some of the pigs when it is still in the container, compared with straw on the floor, the effect on tail biting might differ. Haylage was chosen over straw for the elevated spherical metal grid, as earlier studies indicated that pigs prefer a more complex material over straw as an enrichment material (reviewed by Studnitz et al. (2007)). Giving the material in a spherical cage in the middle of the pen required pigs to work more before the material could be rooted on the floor, but providing the material in a 'container' opens the possibility to apply the material in a certain area of the pen. It may even be possible to provide the material in pens without solid floor, if a creep is placed beneath. In study III it was decided to place the spherical cage over the solid floor to investigate if given haylage in a cage hanging over the floor in the middle of the pen could prevent tail biting outbreak. Another approach in future studies could be to allocate straw in the spherical metal grid, as farmers likely would prefer to use straw over haylage, as straw is cheaper and easier to store.

Sample size and data analyses

The studies included in this thesis were conducted on two different conventional piggeries. Before data collection, power calculations were made to estimate the sample size to find the expected differences.

In study III, the effect of each early intervention treatment was compared with the control treatment with no intervention. Including more pens would have made it possible to compare the different early intervention treatments. However, when Study III was planned, it was not known if the first tail damaged pigs could be realized before an outbreak with the three weekly tail inspections from outside the pen. Furthermore, it was not clear, if providing enrichment at this point could reduce tail biting outbreaks. It was, therefore, decided that the first step was to examine if providing enrichment as early intervention could reduce the prevalence of tail biting outbreaks.

In study III and IV, the effect of treatment was analysed by comparing the prevalence of tail biting outbreaks. Another way to analyse data could have been by using 'time-to-event' analyses. This type of analyses would have made it possible to examine if the type of treatment influenced the time until an outbreak, and would have made other types of conclusion possible. For instance, if a tail biting outbreak occurred within a couple of days after the intervention, the treatment did not manage to stop the tail biting. However, if a tail biting outbreak did not occur until later in the growth period, other circumstances might have been the reason for the increased level of tail biting at that point. Perhaps, other stressors triggered the behaviour, or the intervention did not stay attractive enough over time to avoid tail biting. However, to conduct such kind of analyses larger sample sizes are needed, since a larger variation in the outcome would be expected.

In study II-IV the experimental unit was the pen as tail biting outbreaks are typically handled at pen level in practice. However, including observations at the pig level could have added information on for example how different types of enrichment affected the behaviour of the individual pig. In these cases, especially the behaviour of the biting pigs could increase the knowledge on how enrichment allocation affects the behaviour of these pigs.

5.2 Tail damage – docked vs undocked pigs

Two hypotheses were examined in study I: 'The prevalence of tail damaged pigs is substantially higher in pens with undocked pigs than in pens with docked pigs in a conventional piggery' and 'More pigs with undocked tails receive a tail lesion remark at the abattoir than tail docked pigs'.

Tail damage prevalence - farm

In study I, 23 % of the undocked pigs distributed in 68 % of the pens received a tail injury, whereas no tail docked pigs received a tail injury. These results are supported by another Danish study reporting a lower prevalence of tail damage if half the tail was docked compared to undocked tails (Larsen et al., 2017). However, as discussed in Section 2.5, previous studies also reported increased prevalence of tail damage if only half the tail was docked compared to shorter tails (Scollo et al., 2016; Thodberg et al., 2018), and Thodberg et al. (2018) reported no difference in tail damage between pigs with half docked tails (as in study I) and pigs with undocked or longer tails. Thodberg et al. (2018) was conducted in Danish piggeries with tail biting problems among tail docked pigs, whereas study I was conducted in a piggery with low prevalence of tail damage among tail docked pigs. The differing results indicate, that docking length influence the risk of tail damage, but the effect of docking length may also be influenced by the overall tail damage prevalence among tail docked pigs.

With the tail damage prevalence reported in study I among undocked pigs daily provided with straw, it could be, when taking the pain experienced at tail biting into consideration, as discussed in Section 2.4, that the animal welfare was better among the tail docked pigs? The overall level of animal welfare is, however, a balance between tail docking all pigs and lower prevalence of tail damaged pigs versus no tail docking, higher levels of tail damaged pigs and likely improved housing conditions (more access to enrichment, more space, better feeding and management etc.). However, before making any conclusions regarding the overall animal welfare, experimental studies measuring these elements should be conducted. Also, in the absence of any unifying metric of animal welfare, the tradeoff between these elements is always going to be a judgment call in terms of which scenario is better for welfare overall.

At pig level, a tail damage prevalence of 23 % was relatively low when compared to other studies with undocked pigs. In other studies, the prevalence varied greatly from 11.4 % to 89 % (36.9/46.9 % (Veit et al., 2017); 41/89 % (Li and Johnston, 2017); 34 % (Zonderland et al., 2008); 45.3/83.4 % (Ursinus et al., 2014a); 22.2 % (Di Martino et al., 2015); 11.4 % (Sinisalo et al., 2012)). These differences between studies are likely due to different experimental settings, and thereby different risk factors influencing the tail biting (Taylor et al., 2010; D'Eath et al., 2014).

Results further demonstrated that the prevalence of tail damaged pigs decreased at the end of the finisher period (60 to 90 kg) in study I. This finding is supported by other studies reporting a higher incidence at the beginning of the finisher period (Di Martino et al., 2015; Larsen et al., 2017). This could suggest that in the finisher period there is a higher risk of tail biting in the beginning and maybe by reducing tail biting risk factors in this period would have a large impact on the overall prevalence.

Tail damage prevalence - abattoir

At the abattoir, 2 % of the undocked pigs and 0.3 % of the docked pigs received a tail lesion remark during the routine meat inspection. These numbers indicate that abattoir recordings to a large degree underestimate the on-farm prevalence of tail damage when pigs are not tail docked (11.5-fold difference). Furthermore, there was no compliance between on-farm and abattoir recordings as none of the tail docked pigs were scored with tail damage on the farm. The reason for this could be that the tail docked pigs recorded with a tail lesion at the abattoir got a tail injury during transportation or in the stable at the abattoir.

As discussed by Nielsen et al. (2015), meat inspection data are collected with the purpose of safeguarding food and not with the purpose to estimate the true prevalence of animal welfare indicators. Nielsen et al. (2015) reported a lower prevalence of chronic pericarditis, chronic pleuritis and lungs with a lesion when estimated at routine meat inspection than when estimated at a systematic recording of heart and lungs at a laboratory. This difference between recording methods is in accordance with Keeling et al. (2012). They reported 7.0/7.2 % tail damaged pigs (undocked) at the abattoir when specific observers recorded tail damage, whereas the routine meat inspection recorded 1.2/1.6 % tail damaged pigs in the same period. For this reason, the prevalence of tail injuries and the welfare impact of tail injuries should not be evaluated based on routine meat inspection recordings at the abattoir.

Two previous Danish abattoir surveys reported 0.70 % (Kongsted and Sørensen, 2017) and 0.85 % (Alban et al., 2015) tail damaged pigs at meat inspection amongst tail docked pigs. For comparison, 1.0 % of the pigs were scored with a severe lesion at the abattoir in an Irish study with 99 % tail docked pigs (Harley et al., 2012). As expected, these figures were slightly higher than for the tail docked pigs in study I, as the piggery chosen for the study was selected based on low tail damage prevalence among tail docked pigs. Meat inspection data from a Finnish study reported 1.3 % tail damaged pigs (some pigs might have been tail docked; (Valros et al., 2004)). The figures from the Finnish and the Swedish study mentioned in the first paragraph (1.2 and 1.6 %) are slightly lower than in study I, but at a similar level. This suggests that the level of severe injuries was at the same level as in the Swedish and Finnish study, assuming the same recording procedures in the three countries.

5.3 Behavioural changes before a tail biting outbreak

The hypothesis; 'Changes in behaviour can be used to identify tail biting outbreaks' was addressed in study II.

Results established a correlation between hanging tails and tail damaged pigs in study II and III. Video recordings, obtained in study II, showed more hanging tails in pens close to an outbreak than in control pens without an outbreak. Furthermore, a difference between hanging tails was also identified between days in pens close to a tail biting outbreak – both when observing video and when using direct observations. Video recordings identified more hanging tails on day -1 compared to day -2 and -3 in tail biting pens, whereas the direct observations showed more hanging tails on the day of the outbreak compared to earlier (study II). Additionally, more tails were hanging on day -1 in pens with at least six tail damaged pigs on the day of the tail biting outbreak than in pens with 4-5 tail damaged pigs. These findings were supported by the results in study III showing an increasing number of tail injured pigs with increasing number of hanging tails recorded on the same day using direct observations. The relation was, however, only evident when 20 % or more of the pigs in a pen had a hanging tail, as there was no difference in the number of tail damaged pigs in pens with 0 % and 10 % hanging tails. This is in line with study II, reporting 15 to 17 % hanging tails in control pens. Therefore, other aspects aside from tail biting, likely affected tail posture, as discussed by Larsen et al. (2016). The tails could be hanging in control pens due to pre-injury tail directed behaviour. Furthermore, based on casual observations during data collection, it could be speculated that tail posture is also influenced by the specific behaviour pigs are engaged in. It appeared that pigs rooting the floor often had a hanging tail, while pigs eating or pigs walking around often had a curly tail. However, this should be investigated systematically in future studies before making any conclusions.

At pig level, Zonderland et al. (2009) reported that pigs with the tail down and no tail damage were more likely to have a tail wound 2-3 days later than pigs with a curly tail. Larsen et al. (2016) suggested that pigs exposed to tail directed behaviour in the pre-injury stage experience pain in the tail, and the tail is then lowered to protect it, which could explain the findings in study II and the results of Zonderland et al. (2009).

It was assumed based on earlier findings (Statham et al., 2009; Ursinus et al., 2014a), that the activity level would be higher in upcoming tail biting pens due to increased restlessness caused by the tail biting. Despite these earlier findings, no difference in activity was identified between tail biting pens and control pens in study II, and this is in line with Veit et al. (2016) reporting no relation between overall activity and tail biting. However, several aspects of the definition of activity used in study II could explain the lack of difference between pens. In study II, the activity was measured in the period of the day where pigs were expected to be most active. Differences in activity might have been more pronounced in the resting periods, if the tail directed behaviour disturbed the resting pigs, as reported by Zonderland et al. (2011b). Another reason could be that the activity measure was not detailed enough, since posture changes were not recorded as in Zonderland et al. (2011b) or pigs lying down performing some kind of behaviour were not included in the measure. Perhaps lying pigs were more awake and active in upcoming tail biting pens. Yet, another explanation could be that increasing levels of activity is only evident in pens with severe outbreaks with many tail injured pigs or in pens with continuous tail biting.

Percentage of pigs standing at the feeder did not differ between control and tail biting pens. This finding is in agreement with previous studies. Wallenbeck and Keeling (2013) reported no difference in feeder visits between pigs in tail biting pens and control pens within the week of the tail biting outbreak. This is further supported by Viitasaari et al. (2015) who reported no change in feeder visits by tail damaged pigs from day -2 to day 3 (tail damage was detected on day 0), and Zonderland et al. (2011b) who reported no difference in feeding behaviour between victims and biters from day -6 until day 0 (tail biting outbreak).

Increasing levels of pig-directed behaviour have been suggested as abnormal and as a precursor of tail biting (Van de Weerd and Day, 2009; Ursinus et al., 2014a; Brunberg et al., 2016). However, in a study by Camerlink and Turner (2013), only 0.3 % of the social nosing (2.5 % social nosing in total) was followed by a tail biting, suggesting no correlation between social nosing and tail biting. This is in accordance with the present study finding no difference in pig-directed behaviour between tail biting pens and control pens.

Lack of suitable enrichment materials could be one factor triggering the tail biting (Taylor et al., 2010). It was, therefore, hypothesised in study II that as a reaction to a lack of suitable enrichment materials, pigs would explore their surroundings more before an outbreak. However, no difference in exploration was observed between control pens and tail biting pens. This lack of difference might be explained by the lack of access to attractive enrichment materials – defined as 'manipulable' and 'destructible' (Studnitz et al., 2007). From weaning, pigs had permanent access to two hanging wooden sticks and were daily provided with one scoop of finely chopped straw. These materials might not have been accessible or attractive enough to increase the explorative behaviour before an outbreak. Although this may be true, the lack of difference between pens could also be due to only some pigs increasing their exploratory behaviour prior to an outbreak. Zonderland et al. (2011b) reported biters to explore enrichment material more than control pigs. Likewise, Zupan et al. (2012) demonstrated that biters, tested individually, more rapidly made contact with a novel object and spent longer interacting with it than victims and control pigs. This suggests that biters have a stronger motivation to explore. Altogether, the lack of difference between groups in study II and the findings by others indicates that the differences should likely be found at the individual level and not at pen level as in study II.

In conclusion, there was a large difference in hanging tails between control pens (15 to17 %) and tail biting pens (23 to 33 %) based on video recordings, especially on day -1. Additionally, tail posture also changed in upcoming tail biting pens before an outbreak and direct observation of tail posture could be used to identify pens with an outbreak. Altogether, these results indicate that the measure (changes in tail posture) could be applicable under commercial conditions for use as an indicator of upcoming tail biting outbreaks.

5.4 Effect of early intervention on tail biting outbreaks

The fourth hypothesis; 'Providing pens with extra enrichment, when the first tail damage is observed reduces the risk of a tail biting outbreak' was addressed in study III.

Introducing straw on the floor or haylage in a spherical cage when the first tail damage was observed, reduced the prevalence of subsequent tail biting outbreaks compared to pens not provided with extra enrichment. Additionally, a hanging rope with a sweet block did not reduce the risk of a tail biting outbreak when compared to control pens. However, results should be interpreted with caution as it was a minor study with only few replications.

Compared to haylage and straw, the rope treatment was a fixed material. The material did not disperse on the solid floor as straw and haylage, and pigs could only manipulate the material in a limited area. This might have led to fewer pigs interacting with the rope, leading to the material being less effective in preventing a tail biting outbreak. However, in an operant conditioning study (investigating the pigs motivation or preference for a certain material), the rope was, ranked at the same level as chopped straw and seed grass hay (Jensen and Pedersen, 2007). This suggest that pigs find rope attractive, and it might be that the restricted accessibility in study III was the reason why rope did not reduce tail biting outbreaks to the same extent as straw and haylage. Maybe, rope would have had the same preventive effect as straw and haylage, if two or more pieces were provided. A sweet tasting licking block was attached to the rope to increase attractiveness, because of pigs' preference for sweet flavours (Day et al., 1996). Perhaps the rope would have been more attractive if the rope itself tasted sweet and thereby combining sweet flavour with a destructible material.

Providing straw (approx. 7 g/pig) and haylage (approx. 20 g/pig) as an early intervention, just when the tail biting had started ensured novelty and thereby attractiveness of the material (Studnitz et al., 2007; Trickett et al., 2009; Perre et al., 2011). Using manipulable materials as early intervention may provide the ability that less material or other kinds of materials can prevent tail biting outbreaks compared to when allocated as a permanent preventive measure.

The positive effect of the early interventions also raises the question of whether providing extra enrichment in high-risk tail biting pens (as an early intervention) can prevent tail biting outbreaks to the same extent as permanent access to the same kind of enrichment. If providing extra enrichment to high-risk tail biting pens or in high-risk periods can prevent tail biting outbreaks to the same extent as permanent access, this could be of practical relevance for pig producers.

An age-period not included in the PhD project was the suckling period. Van de Weerd et al. (2005) investigated the effect of providing enrichment during the suckling period (rooting box, liquid dispenser, straw bedding vs none) and during the growth period enrichment (straw bedding vs Bite-Rite). They did not find a link between enrichment in the suckling period and tail damage later in the growth period and suggested that perhaps the current environment and the possibility to explore have a higher impact on tail biting than earlier enrichment. In contrast, a Finnish study reported that access to enrichment (rope/paper/plastic ball/wood shavings vs plastic ball/wood shavings) in the suckling period reduced the severity of tail damage later in the growth period (enrichment: rope, plastic chewing toy and wood shavings; (Telkanranta et al., 2014b)). However, the different enrichment treatments in the suckling period did not affect the total number of tail damaged pigs. An aspect of future research could be to compare the effect of current or previous access to enrichment on the prevalence of tail biting outbreaks.

5.5 From one tail damage to a tail biting outbreak

In study III a tail biting outbreak developed in 42 % of the control pens 2 to 5 days after the first pig was observed with tail damage. For comparison in two previous studies, the transition time from the first tail damaged pig to a tail biting outbreak was between 0.5 and 12 weeks in a finisher study (Statham et al., 2009) and on average 7.5 days (SD 5.4 days) in a weaner study (Zonderland et al., 2008). In Statham et al. (2009) tail biting outbreaks were defined as either 'underlying outbreaks' or 'severe outbreaks' (two bleeding tails, 6.7 % of the pigs). In Zonderland et al. (2008) 20 % of the pigs in a pen (two pigs) should have tail damage, and at least one fresh wound should be present. These differences in the definitions likely influenced the transition times. However, regardless of definitions, the considerable variation in transition time between studies from a solitary tail damage to a tail biting outbreak, indicate that low levels of tail biting may not in every case escalate into an outbreak within a few days. This is supported by Larsen (2018) reporting a non-bleeding wound in 50 % of the finisher pens (undocked tails) without a tail damage incidence (one bleeding wound) within the following seven days.

5.6 Effect of providing extra enrichment in pens with tail biting outbreaks

The last hypothesis; 'In pens with a tail biting outbreak straw provided on the floor or rope lying on the floor prevents a further escalation in tail injuries better than a Bite-Rite' was examined in study IV.

There were no pens without an intervention included in this part of the study, as not to compromise animal welfare, an intervention was assigned to all pens with a tail biting outbreak. The Bite-Rite was included as the negative control group, as it was expected that rope and straw (due to the materials destructibility and manipulability) would more likely stop the tail biting. However, a Bite-Rite could be provided in all type of pens irrespective of floor design, which made it relevant to examine in the study.

The results from study IV demonstrated that providing straw on the floor reduced the risk of a further escalation in tail damaged pigs more efficiently than a Bite-Rite, but there was no difference between pens provided with a hanging rope and Bite-Rite or straw. For comparison, Zonderland et al. (2008) reported that straw (20 g/pig/day) and removing the biter stopped the tail biting equally well. However, in the study by Zonderland et al. (2008), 11 % of the pigs had fresh wounds ten days after the intervention, indicating that the treatments did not entirely stop the biting behaviour, as discussed on Section 2.8.

Even though a small amount of straw reduced the risk of an escalation in tail damaged pigs when compared to Bite-Rite, the tail biting still escalated in 26 % of the pens provided with straw. May be other intervention strategies stops the tail biting more efficiently. This could be: removing tail damaged pigs, removing the biter, providing more material, shifting between different materials or providing other types of material. Increasing the amount of straw has been reported to increase the time pigs interacted with the material (Oxholm et al., 2014; Jensen et al., 2015). There is, however, an increased risk of blocking up the slurry systems with increasing amount of straw. Oxholm et al. (2014) reported that four versus one daily allocation of the same quantity of straw increased the amount of straw left in the pen the following day. Frequent allocation of smaller amounts of straw might be workable under conventional conditions since more straw is consumed and less is wasted in the slurry system. Another approach could be to provide straw in a rack, which would increase the time straw was available and potentially increase the occupational value, since pigs must pull the straw from the rack before they can root it on the floor. However, as discussed by Zonderland et al. (2008) straw in a rack might not be as useful as straw on the floor, if pigs cannot pull the straw from the rack and on to the floor. The design of the rack should therefore be taken into consideration when used in the prevention of tail biting (Van de Weerd and Day, 2009).

There was no difference in the escalation in tail biting between pens provided with rope and Bite-Rite. The effect of the rope treatment might have been improved if a knot was not tied close to the end. When rope beneath the knot was consumed, the material was no longer destructible, until the following day when new rope was provided, which might have resulted in less interest in the material (Bracke, 2007; Studnitz et al., 2007). In the early intervention study (study III) the first knot on the rope was placed just beneath the licking block, which gave pigs more manipulative rope to chew. As discussed earlier, it could be that continuous access to destructible rope without knots or several pieces of rope in each pen are needed to increase the efficiency of the material in pens with tail biting.

Different motivations likely trigger different types of tail biting (Section 2.2), as is the case for mild and severe feather pecking in laying hens (Nicol, 2018). The most effective prevention and intervention might therefore also differ between outbreaks. As for feather pecking (Nicol, 2018), the exact mechanism in pigs triggering the switch from non-damaging behaviour to the damaging behaviour is not understood. However, irrespective of animal species a steady low-stress housing environment is very important to reduce the damaging behaviour. Providing extra enrichment to pigs reduces the risk of tail biting, but does not eliminate the behaviour completely (Section 2.7). This could be due to that the original motivation for tail biting might be something else than lack of material to explore. Birds and pigs are omnivorous species eating many different feed items in nature, whereas domesticated animals of the same age are all offered the same kind of feed. It might be that together with individual coping strategies and housing environment, the reason why pigs and birds start to tail bite/feather peck is due to lack of specific nutrients in the diet (Brunberg et al., 2016). This could also explain the occurrence of both feather pecking and tail biting in more extensive systems, such as in organic production systems (Alban et al., 2015; Bestman et al., 2017). This field of research needs more attention in future studies.

5.7 Characteristic of victims

Characteristics of tail biting victims were addressed both in study I and IV. More castrated males were recorded with tail damage in study I, whereas no difference between sex was observed in study IV. Previous studies also report conflicting results regarding the importance of sex. In some studies reporting tail damage on farm, castrated males/boars were more likely to become victims of tail biting (Van de Weerd et al., 2005), whereas in others they were not (Zonderland et al., 2010; Sinisalo et al., 2012; Di Martino et al., 2015). Recordings from abattoir studies are more in agreement concluding a higher prevalence of castrated males among tail injured pigs (Valros et al., 2004; Kritas and Morrison, 2007; Keeling et al., 2012) as in study I. This difference between abattoir and on-farm recordings could be due to males receiving more severe tail injuries (Kritas and Morrison, 2004), which increases the risk of having a damaged tail at slaughter (Keeling et al., 2012).

Victims with mild or moderate tail damage had higher weight gain than pigs without tail damage (study IV). In contrast, Sinisalo et al. (2012) reported that non-victims had a higher average daily weight gain than victims (recorded by stockpersons) in the finisher period. Wallgren and Lindahl (1996) reported in a minor study (37 pigs) that severe tail damaged fattening pigs (pigs treated with antibiotics due to tail injuries) had reduced weight gain during the biting period, whereas the overall weight gain during a lifetime was not affected. It could be that the severity of the tail injuries in study IV did not reach a point where the injury affected eating behaviour, which was supported by video observations in study II.

5.8 Practical implications

Within the EU 257 million pigs were slaughtered in 2016 (EC, 2017) with the majority being tail docked (EFSA, 2007). In Denmark, 31.8 million pigs were produced in 2017, of which 17.7 million were slaughtered in Denmark, and 14.1 million were exported at 30 kg live weight (DAFC, 2018). Approximately 98.5 % of the 31.8 million pigs produced in Denmark were tail docked (EC, 2018). The experiments in this thesis were conducted in Danish commercial piggeries. The results, however, can be/are of value in other countries with housing systems like the Danish.

In today's production systems where the majority of pigs are tail docked, approximately 3 % of the pigs receive a tail injury (reviewed by D'Eath et al. (2016)). Results from study I showed that approximately one in four undocked pigs got a tail injury in a system with daily provision of straw and low stocking density during rearing, whereas none of the tail docked pigs got a tail injury. Therefore, to avoid a considerable increase in tail damage among pigs produced in the EU, management routines and housing systems should be improved before undocked tails can be fully implemented, as the tail damage prevalence was fairly high among undocked pigs in a system, which beforehand was evaluated as a low-risk conventional tail biting piggery. In a Finnish survey, farmers reported a tail damage level of on average 2.3 % (range 0 to 30 %) among undocked pigs (Valros et al., 2016), which is considerably lower than in Study I. Unfortunately, tail injuries were not recorded systematically by the Finnish farmers, which likely affected the prevalence of tail damage incidences and makes the two studies difficult to compare. However, if the prevalence is much lower in Finland than in Study I, the explanation could be; better trained stockpersons to look for early signs of tail biting, higher health status in the herds, more or different kinds of enrichment, different feeding methods, lower stocking density or a combination of these.

To reduce the pain and stress associated with tail biting and thereby the risk of reduced animal welfare it is essential to reduce the prevalence and severity of tail biting outbreaks. One way to reduce the number of pigs getting a tail injury, is to detect the tail biting in its early stages. Convincingly results from this thesis demonstrated, with the tail biting outbreak definition used, that changes in tail posture from curly to hanging is a promising tool to identify upcoming tail biting outbreaks. The changes in tail posture were so evident that it could be observed from outside the pen. Therefore, perhaps the changes in tail posture can be detected during the daily health inspections in practise without a systematic examination of every tail? Furthermore, by observing tail posture and tail ends from outside the pen, the results from study III, demonstrated that the first minor tail damage could be detected and providing extra enrichment at this point, reduced the risk of tail biting outbreaks markedly.

A constant focus on reducing tail biting risk factors and implementation of knowledge obtained in this thesis, regarding changes in tail posture and early intervention, will likely reduce the incidences of tail damage and tail biting outbreaks among undocked pigs in other piggeries as well and thereby the need for tail docking.

The results generated and the experiences gained in this PhD-project have continuously been communicated to farmers, veterinarians and consultants through talks, at workshops, in farmers' magazines, conferences and peer review journals, and at SEGES, Pig Research Centre's website. Furthermore, the knowledge on how to detect future outbreaks and how to react during a tail biting outbreak will be implemented in the Danish guidelines on how to house pigs with intact tails published by SEGES, Pig Research Centre. Additionally, knowledge obtained in this PhD-project has entailed that SEGES, Pig Research Centre is now trying to completely stop tail docking in a pilot project in 6 to 8 conventional piggeries during 2018 and 2019.

6. Conclusion

This PhD project demonstrated that observing for changes in tail posture and providing extra enrichment material when the first tail damage was observed reduced the risk of tail biting outbreaks.

If pigs are not tail docked and management routines and housing remain the same, the first study displayed that approximately one in four pigs received a tail injury when reared at an expected low-risk tail biting piggery. Furthermore, the prevalence of tail injuries noted at the farm differed markedly from tail injuries recorded at the abattoir. Therefore, to evaluate the consequences of not tail docking on animal welfare, tails should be scored on the farm, rather than being based on abattoir meat inspection recordings.

The second and third study established that changes in tail posture from curly to hanging are a promising tool to detect pens with tail biting in the early stages. Additionally, the third study showed that it was possible, with the used definition of an outbreak, to prevent tail biting outbreaks by providing commercially applicable enrichment materials as early intervention to the pen when the first tail damaged pig was observed.

If pigs are not tail docked, more tail biting outbreaks will occur, as not all tail biting will be detected in the early stages. A small amount of straw prevented an escalation in tail damaged pigs more efficiently than a Bite-Rite in pens with an outbreak, but no difference was observed between rope and straw or Bite-Rite. However, even in pens provided with straw, an increase in tail damaged pigs appeared in approximately one of four pens. There is therefore a need for more experimental studies on more effective intervention strategies in pens with on-going outbreaks.

In conclusion, tail biting is a complex problem. It has been a challenge within the pig industry for many years and will remain a challenge in the years to come. To reduce the negative welfare impact of tail biting when pigs are not tail docked, it would be valuable, aside from a constant focus on minimising risk factors, to identify and stop the behaviour in the early stages. Observing for hanging tails with minor damage during daily inspection and application of extra enrichment, as early intervention when the first tail damaged pig is detected will reduce later tail damage. Altogether, this approach will improve the welfare of pigs, not only by reducing the need for tail docking but also by reducing the prevalence of tail damaged pigs.

7. Perspectives

According to the EU Council Directive (2001/93/EC amendments to Directive 91/630/EEC), since 2003 it has not been legal, by routine, to tail dock pigs. Within recent years an increased pressure has been put on EU member states to reduce the need to tail dock and rear pigs with intact tails (EC, 2016). Rearing pigs with intact tails are, however a challenge due to the increased risk of tail biting and thereby the risk of reduced animal welfare.

Tail biting and tail docking are painful, but tail biting likely inflicts more pain than tail docking and tail docking reduces the risk of tail biting, as discussed in Section 2.4. However, tail docking is a symptomatic treatment and does not remove the environmental stressors triggering the abnormal behaviour. What is worst for the animals – tail docking all pigs or not tail docking with increased levels of tail damage due to tail biting, as discussed by Valros and Heinonen (2015). This depends on the number of tail damaged pigs and the severity of the tail injuries. Is the level of tail damage recorded among undocked pigs in the low-risk tail biting piggery in Study I with a prevalence of 23 % (some severe) better animal welfare than no tail damage among the tail docked pigs? Studies measuring pain and stress at tail docking and tail biting, including an ethical discussion, is needed to answer this question.

This thesis demonstrated that changes in tail posture from curly to hanging tails is indicative of an upcoming tail biting outbreak at the pen level. Furthermore, the change in tail posture was so evident that it could be used to point out pens with tail damaged pigs from outside the pen. Combining, the change in tail posture to point out at risk tail biting pens with an early enrichment intervention will likely reduce the prevalence of tail biting outbreaks. The positive effect of an early intervention gives rise to the question of whether high-value enrichment materials needs to be permanently present or allocated daily to prevent tail biting outbreaks. Future studies should examine if providing extra enrichment in high-risk tail biting pens (as an early intervention) can prevent tail biting outbreaks to the same extent as permanent access to the same type of enrichment. If providing high-value enrichment to high-risk tail biting pens prevents tail biting outbreaks to the same extent as permanent access, this could be of practical relevance for pig producers.

Even though providing extra enrichment to pens with tail damaged pigs reduced the prevalence of tail biting outbreaks, the allocated enrichment did not eliminate outbreaks. This could either be due to that the chosen materials or amount did not reduce the stress level sufficiently to avoid tail biting or that the behaviour was not only triggered by lack of materials to explore. Previous studies also concluded that enrichment materials reduce the risk of tail biting, but does not eliminate the behaviour

(Van de Weerd et al., 2006; Ursinus et al., 2014a; Larsen et al., 2017). Feeding method is a risk factor suggested by farmers to have a high influence on the risk of tail biting (Valros et al., 2016). However, as discussed in Section 5.1, this area of research has only been given little attention. Pigs are highly adaptive animals, but perhaps their instinct to synchronise behaviour and regular diurnal rhythm (Stolba and Wood-Gush, 1989) are important to have in mind in the prevention of tail biting. Overall two different feeding methods exist; ad libitum feeding system with several pigs per eating space and meal feeding with one pig per eating space. In systems with one eating space per pig, pigs can eat simultaneously, whereas this is not possible in systems with several pigs per eating space. Even though the productivity might be the same irrespective of the feeding method, pigs in systems with several pigs per eating space might experience a higher level of stress as they cannot synchronise their eating behaviour. If, how and how much feeding method influence the risk of tail biting needs attention in future studies.

More tail injuries were observed when pigs weighed 7 to 30 kg and 30 to 60 kg than between 60 to 90 kg, which is in line with a previous finisher study (Larsen et al 2017). To avoid tail biting outbreaks, when preventive measures are tested, it might be important to take the age of the pigs into account. Perhaps, the age of the pigs influences the effect of a preventive measure, such as enrichment material, on tail biting. Maybe pigs are less resistant to environmental stressors in certain periods of their life or have a higher need to perform exploratory behaviour than in others. Providing extra enrichment in these more sensitive periods might reduce tail damage, while in other periods the same material will have no effect. Furthermore, perhaps the impact of a specific tail biting risk factor is influenced by pigs' age? Risk factors influence depending on age requires more attention in future studies.

Apart from preventing tail biting and stopping the behaviour once started with an intervention, it is also important to have the welfare of the victims' in mind; should victims be removed from the pen or stay? There are pros and cons to removing a pig, and this is always a balance. If an intervention completely stops further biting, then the tail injured pig should be able to recover well in the pen. If the pig remains at risk of further injury, it might be better to remove the pig, but then there is a potential for isolation stress or social stress if placed in a new group due to increased aggressiveness (Stukenborg et al., 2011). The other type of pig to have in mind is the biter. To avoid further biting the biter is (if located) removed (Valros et al., 2016), but should the biter be removed to another group of pigs with the risk of continuous biting or should it be isolated? Another approach in future research could be to reduce the prevalence of biters. If the internal motivation is the same for the 'obsessive biters' as for other biting pigs (as discussed in Section 2.2), it might be that by detecting the tail biting and stopping the behaviour before an outbreak occurs, then fewer pigs would develop into biters. If early intervention is conducted, just when the biting has started, the intervention may also more successfully reduce stress levels in more sensitive pigs (upcoming biters), and fewer pigs will become actual biters.

If pigs were not tail docked with the current management routines and within the current housing systems, the best piggeries would likely have a tail damage prevalence at the same level as the piggery in the first study (23 %). If 3 % of the tail docked pigs get a tail injury in current production systems (D'Eath et al., 2016), not tail docking would lead to an approximately 8-fold increase in tail injured pigs. Assuming all pigs produced within the EU (257 million; (EC, 2017)) are not tail docked this would lead to an increase of 51.4 million tail injured pigs costing the industry €975 million annually, giving the cost of one tail injured pig to be €18.96 as estimated by D'Eath et al. (2016). However, if changes in tail posture, as an early warning sign, had been included in study I together with an early intervention when the first tail damaged pig was observed, fewer pigs would likely had got a tail injury. Future studies should therefore investigate the overall effect of early detection by stockpersons followed by an intervention on tail damage prevalence and tail damage severity in conventional piggeries.

Work from this thesis demonstrated that improving management procedures - by looking for changes in tail posture and reacting to these changes by providing extra enrichment - reduced the prevalence of tail biting outbreaks. However, more knowledge on how different risk factors influence tail biting and how to prioritize these to efficiently prevent tail biting needs to be examined in future work. Tail biting is a complex problem, but by a systematic approach with a continuous focus on trying to understand the origin of the behaviour will reduce the prevalence. Given the complexity no simple solution to the tail biting problem exists and the best way forward is to try to understand the behaviour of the pigs.

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9. Papers

Paper I

Lahrmann H.P., Busch, M.E., D'Eath, R., Forkman, B., Hansen, C.F. 2017. More tail lesions among undocked than tail docked pigs in a conventional herd., Animal 11, 1825-1831.

Paper II

Lahrmann, H.P., Hansen, C.F., D'Eath, R., Busch, M.E., Forkman, B. 2018. Tail posture predicts tail biting outbreaks at pen level in weaner pigs., Applied Animal Behaviour Science 200, 29-35.

Paper III

Lahrmann, H.P., Hansen, C.F., D'Eath, R.B., Busch, M.E., Nielsen, J.P., Forkman, B. Early intervention with enrichment can prevent tail biting outbreaks in weaner pigs. 2018. Livestock Science 214, 272-277.

Paper IV

Lahrmann, H.P., Hansen, C.F., D'Eath, R.B., Nielsen, J.P., Forkman, B. Comparing straw, rope and Bite-Rite as treatments for tail biting outbreaks in weaner pigs. In prep manuscript.

9.1 Paper I

Lahrmann H.P.[1], Busch, M.E.[1], D'Eath, R.[2], Forkman, B.[3], Hansen, C.F.[3,*] 2017. More tail lesions among undocked than tail docked pigs in a conventional herd., Animal 11, 1825-1831.

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More tail lesions among undocked than tail docked pigs in a conventional herd

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The vast majority of piglets reared in the European Union (EU) and worldwide is tail docked to reduce the risk of being tail bitten, even though EU animal welfare legislation bans routine tail docking. Many conventional herds experience low levels of tail biting among tail docked pigs, however it is not known, what the prevalence would have been had the pigs not been tail docked. The aim of this study was to compare the prevalence of tail lesions between docked and undocked pigs in a conventional piggery in Denmark with very low prevalence of tail biting among tail docked pigs. The study included 1922 DanAvl Duroc × (Landrace × Large White) female and castrated male pigs (962 docked and 960 undocked). Docked and undocked pigs were housed under the same conditions in the same room but in separate pens with 20 (±0.03) pigs/pen. Pigs had ad libitum *access to commercial diets in a feed dispenser. Manipulable material in the form of chopped straw was provided daily on the floor (~10 g/pig per day), and each pen had two vertically placed soft wood boards. From weaning to slaughter, tail wounds (injury severity and freshness) were scored every 2nd week. No clinical signs of injured tails were observed within the tail docked group, whereas 23.0% of the undocked pigs got a tail lesion. On average, 4.0% of the pigs with undocked tails had a tail lesion on tail inspection days. More pens with tail lesions were observed among pigs weighing 30 to 60 kg (34.3%;* $P<0.05$*) than in pens with pigs weighing 7 to 30 kg (13.0%) and 60 to 90 kg (12.8%). Removal of pigs to a hospital pen was more likely in undocked pens (*$P<0.05$*, 47.7% undocked pens and 22.9% docked pens). Finally, abattoir meat inspection data revealed more tail biting remarks in undocked pigs (*$P<0.001$*). In conclusion, this study suggests that housing pigs with intact tails in conventional herds with very low prevalence of tail biting among tail docked pigs, will increase the prevalence of pigs with tail lesions considerably, and pig producers will need more hospital pens. Abattoir data indicate that tail biting remarks from meat inspection data severely underestimate on-farm prevalence of tail lesions.*

Keywords: pigs, tail biting, tail docking, housing, behaviour

Implications

Most growing pigs within the EU are tail docked to prevent tail biting. We studied a farm which routinely tail docks and had a very low tail biting prevalence. For this study, tail docking was ceased in half the pigs. The results indicate that even in such a low prevalence herd, keeping pigs with undocked tails increases the tail damage prevalence significantly, particularly in 30 to 60 kg pigs, and as a consequence more hospital pens are needed for tail bitten pigs. Also, our data show that abattoir estimates of tail damage prevalence are likely to greatly underestimate on-farm prevalence.

Introduction

The majority of pigs reared worldwide are tail docked to reduce the risk of being tail bitten (EFSA, 2007). This is also the case in the EU despite animal welfare legislation banning routine tail docking (2001/93/EC amendments to directive 91/630/EEC). Despite the tail docking procedure, tail lesions still occur, variously suggested as affecting around 1% to 2% (Zonderland *et al.*, 2011a) to 3.1% (D'Eath *et al.*, 2016) of the pigs. If pigs within the EU are to be kept with undocked tails in existing housing systems with no change in management, it will most likely lead to a dramatic increase in tail bitten pigs (EFSA, 2014). A 50% increase in severe lesions has been suggested (Valros and Heinonen, 2015), and recent calculations stated 17% tail bitten pigs during growth, if pigs are to be housed with undocked tails in today's conventional systems (D'Eath *et al.*, 2016). On the other hand, Finnish farmers, producing pigs with intact tails, reported in a survey an estimated tail lesion prevalence of 2.3% (median 1%, range 0% to 30%) on farm (Valros *et al.*, 2016). However, these estimates need further evidence-based confirmation. In most studies, levels of tail damage across herds are estimated based on recordings made on pigs at

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slaughter (Valros *et al.*, 2004; Harley *et al.*, 2012; Keeling *et al.*, 2012). However, using abattoir meat inspection recordings to determine the level of tail bitten pigs in herds will probably underestimate the number of bitten pigs (Keeling *et al.*, 2012).

The first step towards a general termination of tail docking is to investigate the consequences of housing undocked pigs in conventional herds with low levels of tail biting among tail docked pigs. Based on existing knowledge and risk factors related to tail biting behaviour (Taylor *et al.*, 2012), it could be assumed that tail biting behaviour will be less prevalent in such herds. Consequently, if tail biting increases significantly in herds with a low level of tail biting among tail docked pigs, it will most likely be very difficult to house pigs with undocked tails in other herds as well, without a dramatic increase in tail bitten pigs.

The aim of the present study was to quantify the level of tail lesions between pens with docked and undocked pigs housed under the same conditions in a herd with very low tail biting prevalence among tail docked pigs. No pre-emptive adjustment of current housing was carried out, because tail biting among tail docked pigs occurred very infrequently in the herd and pigs were routinely provided with manipulable materials in the form of straw and wooden boards.

Material and methods

This study was conducted in accordance with the guidelines of the Danish Ministry of Justice Act no. 382 (10 June 1987), Act no. 333 (19 May 1990), Act no. 726 (9 September 1993) and Act no. 1016 (12 December 2001) with respect to animal experimentation and care of animals under study.

The study was carried out at a commercial Danish farm (Vrå, Denmark) from March 2014 to August 2015. The farm was selected based on low prevalence abattoir tail biting remarks. Meat inspection data before the study (1 year) reported tail biting remarks of 0.37% for the tail docked pigs. In addition the farmer and his advisor reported that they very infrequently experienced tail biting in the herd. The management system was also considered low-risk as regards to tail biting due to the daily provision of straw (Taylor *et al.*, 2012).

Housing and experimental design

In total, 960 undocked and 962 docked (906 females, 948 castrated males and 68 unknown gender) Danish Duroc × (Landrace × Yorkshire) pigs from 12 batches were included in the study: 47 pens with undocked tails and 48 pens with docked tails. In all, 20 (±0.03) pigs were randomly allocated (48% gilts/pen, ±1.5%) to each experimental pen housing undocked and docked pigs separately. A period of 2 weeks after arrival, the farmer moved one or two of the smallest pigs from each pen to a buffer pen at which point these pigs were excluded from the experiment.

Piglets were born at a different location in farrowing pens with crates. Every 5th week, 10 to 18 litters were randomly allocated to one of two treatments (groups): tail docked or undocked. On the day of birth, piglets had the tip of their needle teeth removed by grinding. At 4 days of age, piglets in the 'docked group' were tail docked (half the tail). All piglets were given iron injections (Uniferon; Pharmacosmos, Holbæk, Denmark), and male piglets were surgically castrated and given a short-term analgesic. From 10 days of age, piglets were offered creep feed on the floor. No additional enrichment was provided for the piglets in the farrowing pen.

All pigs were ear tagged and their gender noted 1 week before weaning. Piglets were weaned on average 26 (±2.3) days after birth and moved to pens, where they were housed for 2 days before being transported to the experimental farm. Docked and undocked pigs were housed in separate pens within the same room. Within the group, pigs were allocated randomly to the pens. Pens were designed with two climate zones, with solid floor and a cover in the lying area and slats in the dunging area. Pigs had *ad libitum* access to a diet based on spring barley, wheat, fat and 30% concentrate (Danstart VP30; Vilomix, Mørke, Denmark).

The experimental farm consisted of four identical rooms with 36 pens/room of which 6 to 13 pens/room were included in the study. Pens measured 2.4 × 5.0 m (12 m^2) with 4.8 m^2 solid floor and 7.2 m^2 slatted floor (Figure 1). A 2.16 m^2 cover was placed 1 m above the solid floor. Two pens shared a dry feed dispenser with a 62 cm long trough and two nipple drinkers (Figure 1).

At the weaning accommodation and at the experimental farm, each pen was equipped with two vertically mounted wooden pine boards measuring 38 × 57 × 100 mm standing on the floor in a retainer as manipulable material.

Climate

The indoor climate at the experimental farm was regulated by a negative pressure ventilation system (SKOV A/S, Glyngøre, Denmark) supplemented with ceiling air inlets. The ceiling air inlets opened when the room temperature was 2°C above the set temperature. At arrival at the experimental

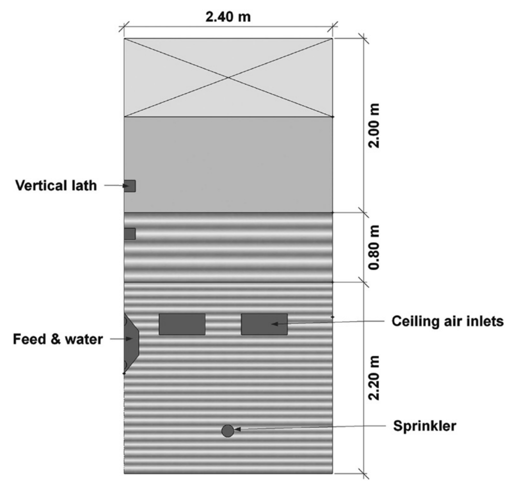

Figure 1 Experimental pen design.

Table 1 *Potential physiological energy, CP and lysine content in commercial diets*

Live weights	7 to 9 kg[1]	9 to 17 kg[2]	17 to 35 kg[3]	35 to 55 kg[4]	55 to 90 kg[5]
Potential physiological energy (MJ)	8.5	7.9	7.8	7.9	7.7
CP (%)	18.4	17.7	18.3	16.5	14.7
Lysine (%)	1.3	1.2	1.2	1.0	0.88

[1 to 5]Hedegaard A/S, Nørresundby, Denmark.
[1]Minigris L-3.
[2]Maxigris L-7.
[3]Maxigris voks.
[4]Svine-voks primo.
[5]Svine-voks sludeal.

farm (day 0), the set room temperature was 24°C, and the temperature was gradually decreased during the growing period to 17°C on day 112 when the study ceased. Two heating pipes placed along the wall in either side of the room were regulated by the ventilation system. In addition, thermostatically controlled floor heating in the lying area was turned on when the pigs arrived, resulting in a floor temperature of 35°C to 37°C. The floor heating was usually turned off around day 25.

Feeding
Pigs were fed with five different commercial compound diets (Table 1) formulated to fulfil the Danish recommendations for pigs of this weight and genotype (Tybirk *et al.*, 2016). From 7 to 9 kg (~10 days), pigs were floor fed four times a day (semi *ad libitum*). From ~9 kg until slaughter pigs had *ad libitum* access to feed in a dry feed dispenser.

Management
Each day, pigs were inspected twice: at around 0900 and 1730 h. Pigs' health condition was monitored, and pigs with clinical signs of disease were recorded by the stockperson and treated with an antibiotic. In the study period, pigs were treated for diarrhoea, tail lesions, locomotion disorders, respiratory diseases, brain/nerve disorders and other reasons (none of the above mentioned). Unthrifty pigs, pigs with locomotion disorders or serious tail lesions (more than half the tail missing for undocked pigs) were either euthanised or moved to hospital pens. The farmer recorded the reason for euthanasia/death and transfer to hospital pens.

Throughout the study period, pens were provided daily with ~230 g of chopped wheat straw on the floor. In case the solid floor got soiled due to defecation, the straw allocation stopped. This could happen, when pigs weighed around 70 kg.

Tail biting management
If tails were clinical injured, a Bite-Rite (Ikadan Systems A/S, Ikast, Denmark), consisting of four elastic plastic sticks, was suspended in the middle of the pen above the slatted floor, and the amount of chopped straw was doubled (~460 g/pen, once daily). The development in tail damages was monitored the following days. Pigs with tails with signs of infection (swollen red tissue) were treated with antibiotic, and pigs with severe tail injuries, defined as half the tail missing, were moved to a hospital pen.

Table 2 *Tail injury scoring system*

	Description
Tail damage	
No	No visible tail lesion. Earlier lesion is healed
Red, clean and/or minor scratches	Tail appears red and/or has minor scratches
Tail wound	Visible wound with obvious tissue damage
Tail length[1]	
Intact	Full length tail
Part missing	A part of the tail is missing
Wound freshness	
Fresh/bleeding	Fresh blood is visible
Dried/scab	Tail wound covered with a scab
Swelling	
No	No swelling
Yes	Swollen red tail indicating an infection

Modified after Kritas and Morrison (2004) and O'Driscoll *et al.* (2013).
[1]Tail length was only recorded for undocked pigs.

Tail damage scoring
Tails were scored every 2nd week from weaning until slaughter according to the scale in Table 2 using four parameters for each tail: Tail damage, tail length (only intact tails), wound freshness and tail swelling. In order to standardise observations, tail scoring was performed by the same trained person throughout the study period. At tail scoring, the observer was walking around in the pen checking each tail.

Statistical analysis
Each pig was categorised as either a tail biting victim or non-victim (binary variable). Pigs scored with a tail wound, irrespective of freshness of the wound, tail length or swelling, were categorised as victims (Table 2). Pigs were divided into three weight (age) groups: (1) weaning (7 to 30 kg, 5 to 12 weeks), (2) grower (30 to 60 kg, 13 to 17 weeks) and (3) finisher (60 to 90 kg, 18 to 21 weeks).

Statistical analyses were performed using SAS Enterprise Guide 7.1. Number of pigs moved to hospital pens, pen level prevalence of tail damage and number of antibiotic treatments were analysed with pen as the experimental unit. For the overall appearance of tail bitten pigs, each individual pig was the experimental unit, and pigs within pens within batches were included as random effects. Number of dead pigs was analysed on batch level.

The effect of weight (age) on tail damage prevalence (binary variable) was analysed using the Generalised Linear Mixed Model procedure (GLIMMIX) with weight as fixed effect and sex, batch and pen as random effects. The effect was analysed using an overall *F* test, and a Student's *t* test for pairwise comparisons of weight groups. Differences in number of dead pigs and antibiotic treatments between docked and undocked pigs were analysed using a Student's *t* test. To compare differences between number of docked and undocked pigs getting a tail biting remark at the abattoir and pens with pigs moved to a hospital pen, a χ^2 test was used. Data are presented as means ± SEM and *P*-values lower than 0.05 were considered significant.

Results

No tail injuries were recorded among tail docked pigs. In contrast, 220 undocked pigs (23% of undocked pigs) distributed in 32 pens (68% of pens) were scored with a tail injury at least once during the study period. In all, 24 tail bitten pigs (10.9%) from 12 different pens were moved to hospital pens. Thus, 89.1% of the tail bitten pigs stayed in the home pen, and the wound healed with the use of Bite-Rite and extra straw as enrichment or removing the biter. Four biters in three different pens were removed during the trial, and three tail bitten pigs moved to a hospital pen had to be euthanized.

Of the 220 tail bitten pigs, 38 were logged twice with a tail lesion in the home pen, and four were logged three times. Injuries on pigs with two or three tail lesion recordings could either be new fresh wounds or scabbed wounds. In other words, aside from pigs moved to hospital pens, the majority of wounds healed within a 2-week period.

On average, 4.0 (±0.7) % of the pigs with undocked tails had a tail lesion at each inspection. These bitten pigs were distributed in 20.9 (±2.2) % of the pens. In addition, 50.0% of the tail bitten pigs were observed within 37 days (up to ~25 kg) after arrival. The recorded tail scores are listed in Table 3. By far the most frequent score (93.8%) was 'part of the tail missing with a scabbed wound'.

More castrated males got tail lesions (124; $F = 13.04$, $P < 0.001$) compared with females (82) with gender information missing for 14 of the tail bitten pigs. More pigs had tail lesions in the weight interval 30 to 60 kg than 7 to 30 kg ($P = 0.026$) and 60 to 90 kg ($P < 0.001$), and fewer pigs between 60 and 90 kg compared with 7 to 30 kg ($P < 0.001$) were observed with tail lesions (Table 4). At pen level, tail lesions were more often present in pens with pigs weighing 30 to 60 kg than in pens with pigs weighing 7 to 30 kg ($P < 0.001$) and 60 to 90 kg ($P < 0.001$) (Table 4).

Pigs with undocked tails increased the need for hospital pens ($P = 0.02$; Table 5). Undocked pigs ($n = 39$) were moved due to: tail damages (61.5%), other reasons (12.8%), brain/nerve disorders (10.3%), locomotion disorders (7.7%) and diarrhoea (7.7%). In total 15 docked pigs were moved due to: brain/nerve disorders (40.0%), other reasons (26.7%), diarrhoea (13.3%), locomotion disorders (13.3%) and respiratory disease (6.7%). No difference in number of dead or euthanised pigs was observed between docked and undocked pigs, but more pigs with undocked tails were treated with antibiotics ($P = 0.02$; Table 5).

Finally, meat inspection data were collected from 853 undocked pigs and 933 tail docked pigs, and more pigs with undocked tails got a tail biting remark during standard meat inspection at the abattoir ($P < 0.001$; Table 5).

Table 3 *Total tail damage frequency (*n = 257*) and distribution (%) among pigs scored with clinically injured tails*

Tail scores	n^1	%
Intact tail, scratches	1	0.4
Intact tail, fresh wound and swollen tail	1	0.4
Part missing and fresh wound	3	1.2
Part missing and scabbed wound	241	93.8
Part missing, scabbed wound and swollen tail	11	4.3

[1]Totally 257 clinically injured tails were recorded on 220 different pigs.

Table 4 *Percentage of pigs and pens with tail lesions among pigs with undocked tails in three weight intervals: 7 to 30 kg, 30 to 60 kg and 60 to 90 kg*

	Weight			
	7 to 30 kg	30 to 60 kg	60 to 90 kg	*P*-value
Tail lesions pig level				
Pigs (*n*)	959	933	919	
Tail lesions per pen (%)	5.0^a (4.0 to 6.1)	6.6^b (5.3 to 8.2)	1.4^c (0.91 to 2.2)	<0.001
Tail lesions pen level				
Pens (*n*)	47	47	47	
Pens with tail lesion (%)	13.0^a (8.2 to 19.9)	34.3^b (24.3 to 46.1)	12.8^a (7.3 to 21.6)	<0.001

95% confidence interval values are within parentheses.
[a,b]Values within a row with different superscripts differ significantly at $P < 0.05$.

Table 5 *Effect of tail docking on pigs moved to hospital pens, dead/euthanised pigs, antibiotic treatments and abattoir tail biting remarks*

	Undocked			Docked			
	n	%	95% CI	*n*	%	95% CI	*P*-value
Pens with pigs moved to hospital pens	21	44.7	–	11	22.9	–	0.02[1]
Dead/euthanised pigs (pigs/batch)	2.6	2.9	1.21 to 4.64	3	3.7	2.32 to 5.01	Ns (0.64)
Started antibiotic treatments per pen	34.1	–	29.3 to 39.0	26.5	–	22.2 to 30.8	0.02
Abattoir tail biting remarks	17	2.00	–	3	0.32	–	<0.001[2]

[1]Pens with pigs moved to hospital pens, $\chi^2 = 5.04$.
[2]Abattoir tail biting remarks, $\chi^2 = 11.24$.

Discussion

This study was designed to compare the tail biting prevalences between docked and undocked pigs from weaning until slaughter. The farm was chosen based on very low tail lesion prevalences among tail docked pigs before the study period. In this study, none of the tail docked pigs got tail lesions, which supports the idea that tail docking can reduce damaging tail biting (Sutherland and Tucker, 2011). The effect of tail docking found in the current study is in agreement with most other studies. Di Martino *et al.* (2015) reported increased risk of tail lesions among undocked fattening pigs (OR = 20.82) compared with tail docked, and Sutherland *et al.* (2009) described more severe tail lesions among undocked pigs. In a survey of Dutch farmers, conventional farmers rearing tail docked pigs stated that tail docking is the most effective way to reduce tail biting (Bracke *et al*., 2013). This need for tail docking received less support from Finnish conventional farmers rearing pigs with undocked tails (Valros *et al*., 2016), with only 21% saying they would tail dock if it was allowed. The differences in attitude towards the need to tail dock between Finnish and Dutch farmers, could be, that Finnish farmers are not allow to tail dock and have considerable experience of managing undocked pigs, and that they have practical knowledge of other solutions to tail biting.

The prevalence of bitten pigs varies greatly between studies, possibly due to different definitions of a tail wound and tail scoring method. For comparison of prevalence between studies, in the following, the definition of a tail wound is stated along each study. Di Martino *et al.* (2015) observed in average 18.6% undocked finishers with mild tail lesions (bite marks/small abrasions), and 3.6% with tail wounds (lesions bleeding and tissue loss). A Dutch study, with undocked weaners reported considerably higher levels, with 54% observed with a tail wound (clearly visible wound with blood) and 35% with bite marks (Zonderland *et al*., 2011b). In another study 83.4% (barren environment – jute sack, ball on a chain, two handful of wood shavings per pen per day) and 45.3% (enriched environment – jute sack, ball on a chain, 12 kg wood shavings at start, 3 kg added daily) of the undocked pigs were reported with a tail wound (clearly visible wound) from weaning to slaughter (Ursinus *et al*., 2014). Among finishers weighing 90 to 100 kg, Cagienard *et al.* (2005) observed on 'animal friendly' farms (straw bedding and access to outdoor facility) 2.8% pigs with a bleeding tail or a part of the tail missing due to tail biting, compared with 21.9% on traditional farms. This suggests that increasing levels of enrichment reduces the level of tail damage. In the present study, pigs were provided with straw daily, which might explain the lower level of tail bitten pigs throughout the growing period compared with some other studies. Overall, the large variation between studies is probably due to variation in any or all of the many distinct risk factors associated with tail biting (Schrøder-Petersen and Simonsen, 2001; D'Eath *et al*., 2014).

Stocking density has been suggested as another risk factor influencing tail biting prevalence (D'Eath *et al*., 2014). Two epidemiological studies concluded that increasing stocking density was associated with an increased risk of tail lesions (Moinard *et al*., 2003; Scollo *et al*., 2016). In our study, pigs were housed in the same pen from weaning to slaughter, giving a lower stocking density in the weaning period (~0.6 m^2/pig) than required according to the EU Council Directive (0.3 m^2 – EU Council Directive 2008/120/EC). This lower stocking density might have influenced the level of tail biting in the weaner group.

Barrows are often more likely to become tail biting victims (Wallgren and Lindahl, 1996; Kritas and Morrison, 2004; Valros *et al*., 2004), and this is in line with the present study. However, some experiments have failed to show a correlation between gender and the risk of becoming a tail biting victim (Zonderland *et al*., 2010; Sinisalo *et al*., 2012; Scollo *et al*., 2013; Di Martino *et al*., 2015). These inconsistencies between studies might be attributed to different grouping strategies and different settings (Sinisalo *et al*., 2012). The reasons why barrows in some studies more often become tail biting victims are not fully understood.

We scored tail damage in every age group from weaning to slaughter, which was also done in a Dutch study (Ursinus *et al*., 2014). In the Dutch study, the percentage of bitten pigs did not decline towards the end of the finisher period in a barren environment. However, a decline in tail bitten pigs, as in our study, was observed among pigs in the end of the finisher period housed in an enriched environment. This decline in tail damages could be due to the fact that severely bitten pigs were moved to hospital pens, or perhaps pigs are reluctant to bite tails when they reach a certain age or weight. In two studies with finishers the exploratory behaviour towards straw (Lahrmann *et al.*, 2014; Oxholm *et al.*, 2014) and activity level declined with age (Oxholm *et al.*, 2014). However, in the same studies, penmate directed behaviours did not decline with age, and increasing levels of penmate directed behaviour has been associated with tail biting (Beattie *et al.*, 2001).

When tail biting occurs, the severity of tail wounds can differ between pigs within the pen. Some pigs only get a bite mark whereas others get actual wounds (Zonderland *et al.*, 2011b). The severity of the wound is expected to affect the healing duration. In our study, 11 pigs got a severe tail lesion with infection (swollen tail) in the home pen. This number would probably be higher if pigs in the hospital pens were tail scored as well. In comparison, 89% of the tail wounds healed successfully in the home pen between two tail inspections, and this indicates, that it is not necessary in every case to remove bitten pigs in order to stop the damaging tail biting behaviour.

Adding extra enrichment as an intervention can stop tail biting to the same extent as removing the biter (Zonderland *et al.*, 2008). In the present study, biters were removed when detected and extra enrichment was added to the pen. The effect of extra enrichment probably depends on the reason why pigs instigate the damaging tail biting. Extra enrichment might be enough to stop the 'two-stage' biting and 'sudden-forceful' biting, if the reason for biting is boredom or frustration due to lack of enrichment, whereas the obsessive biter must be removed from the pen in order to stop the tail biting (Taylor *et al.*, 2010). However, there is a need for more experimental studies looking into the effect of different intervention strategies on the healing of tail wounds, as suggested by D'Eath *et al.* (2014).

Previous studies of mortality rates ranging from 1.7% (Scollo *et al.*, 2013) to 5.5% (Di Martino *et al.*, 2015) corresponding to our findings, have failed to discover differences in overall mortality between undocked and tail docked pigs. However, the results of the present study should be interpreted with caution, as it was not statistically designed for comparing mortality.

In contrast to our findings, no differences in number of pigs moved to hospital pens between docked and undocked pigs were reported by Scollo *et al.* (2013) and Di Martino *et al.* (2015). A likely explanation for the dissimilarity between studies could be different management routines and strategies in the experiments, such as when the tail bitten pigs are moved to hospital pens and the intervention strategies in outbreak pens (moving biter, adding extra enrichment, etc.).

To our knowledge, the current study is the first to compare abattoir tail biting remarks between undocked and docked pigs originating from the same piggery. Comparing on-farm tail wound prevalence (Table 4) with abattoir prevalence (Table 5), indicates that abattoir recordings heavily underestimate the number of undocked pigs being tail bitten. The prevalence of tail lesions was highest among 30 to 60 kg pigs, and these wounds probably healed before slaughter. Healed tail lesions will usually not be recorded during meat inspection, and severely bitten pigs will often be culled in the herd (Taylor *et al.*, 2010), which to some extent explains the differences in prevalence. An adjusted scoring method at slaughter could improve the agreement between herd and abattoir prevalence of tail wounds/bites. In the current study, we observed that healed tips (round and bald) had a different appearance than intact tips (flattened and hairy). In an abattoir, where docked pigs are the norm, meat inspectors may be likely to score previously bitten and now healed tails as though they are 'normal' docked tails.

A Danish abattoir survey of 1 173 213 tail docked pigs reported 0.85% tail damages at meat inspection (Alban *et al.*, 2015), and an Irish abattoir study with 99% tail docked pigs reported 1.03% severe tail lesions (Harley *et al.*, 2012). As expected, these figures are slightly higher than for the docked group in our study, because the trial herd was selected based on low abattoir tail biting remarks among tail docked pigs. Meat inspection data from a Swedish survey (15 068 pigs) with undocked pigs showed tail damage prevalences of 1.2% and 1.6% at two different slaughterhouses (Keeling *et al.*, 2012), which is in accordance with the level in the undocked group in the present study. In agreement with these findings, a Finnish abattoir study reported 1.3% tail damages, though some pigs may have been tail docked (Valros *et al.*, 2004). Even though no tail damage was observed among tail docked pigs during the trial period, a few tail docked pigs did get a tail biting remark at the abattoir. These tail damages could have occurred after the study ended, during transportation or in the abattoir holding pens.

In conclusion, in a conventional herd with low stocking density in the weaning period and daily provision of straw, no tail docked pigs got a tail lesion, whereas 23% of the undocked pigs got a tail lesion. At pig and pen level, tail lesions were more prevalent among 30 to 60 kg pigs than in the late finishing period (60 to 90 kg). More pigs with undocked tails compared with tail docked pigs had to be treated with antibiotics and moved to hospital pens. In particular, the results suggest that caution should be taken when recordings from abattoir routine meat inspection are used to evaluate the level of tail biting in a herd, because this likely highly underestimates the number of bitten pigs.

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9.2 Paper II

Lahrmann, H.P.[1,*], Hansen, C.F.[1], D'Eath, R.[2], Busch, M.E.[1,4], Forkman, B[3]. 2018. Tail posture predicts tail biting outbreaks at pen level in weaner pigs., Applied Animal Behaviour Science 200, 29-35.

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Tail posture predicts tail biting outbreaks at pen level in weaner pigs

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ABSTRACT

Detecting a tail biting outbreak early is essential to reduce the risk of pigs getting severe tail damage. A few previous studies suggest that tail posture and behavioural differences can predict an upcoming outbreak. The aim of the present study was therefore to investigate if differences in tail posture and behaviour could be detected at pen level between upcoming tail biting pens (T-pens) and control pens (C-pens). The study included 2301 undocked weaner pigs in 74 pens (mean 31.1 pigs/pen; SD 1.5). Tails were scored three times weekly (wound freshness, wound severity and tail length) between 07:00 h–14:00 h from weaning until a tail biting outbreak. An outbreak (day 0) occurred when at least four pigs had a tail damage, regardless of wound freshness. On average 7.6 (SD 4.3) pigs had a damaged tail (scratches + wound) in T-pens on day 0. Tail posture and behaviour (activity, eating, explorative, pen mate and tail directed behaviour) were recorded in T-pens and in matched C-pens using scan sampling every half hour between 0800–1100 h 1700–2000 h on day -3, -2 and -1 prior to the tail biting outbreak in T-pens. Further, to investigate if changes in tail posture could be a measure for use under commercial conditions, tail posture was recorded by direct observation from outside the pen. The live observations were carried out just before tail scoring on each observation day until the outbreak. The video results showed more hanging/tucked tails in T-pens than in C-pens on each recording day ($P < 0.001$). In T-pens more tails were hanging on day -1 (33.2%) than on day -2 (24.8%) and day -3 (23.1%). Further, the number of tail damaged pigs on day 0 was correlated with tail posture on day -1, with more tails hanging in pens with 6–8 and > 8 tail damaged pigs than in pens with 4–5 tail damaged pigs ($P < 0.001$). Live observations of tail posture in T-pens also showed a higher prevalence of hanging tails on day 0 (30.0%; $P < 0.05$) than on day -3/-2 (17.2%), -5/-4 (15.4%) and -7/-6 (13.0%). No differences in any of the recorded behaviours were observed between T-pens and C-pens. In conclusion, lowered tails seem to be a promising and practical measure to detect damaging tail biting behaviour on pen level even when using live observations. However, there were no changes in activity, eating, exploration or tail-directed behaviours prior to a tail biting outbreak.

1. Introduction

Damage to pigs' tails due to tail biting has been observed in many different housing systems (Taylor et al., 2010; D'Eath et al., 2014). Today most pigs housed under conventional conditions are tail docked (EFSA, 2007), and research shows that tail docking reduces the prevalence of tail damage (Di Martino et al., 2015; Lahrmann et al., 2017). However, tail docking itself raises welfare and ethical concerns, and the European Commission recommends that pig producers reduce the need for tail docking by reducing the risk factors associated with tail biting and changing their management measures (EC, 2016).

If more pigs are to be housed with intact tails, it is essential that severe tail biting is prevented as discussed by D'Eath et al. (2016). Alongside reducing risk factors, a valuable approach to avoid severe tail biting outbreaks, is to detect and stop damaging tail biting behaviour in its very early stages (Schrøder-Petersen and Simonsen, 2001; D'Eath et al.,2014).

A review by Larsen et al. (2016) described a few experiments investigating whether behavioural changes can predict a tail biting outbreak. These experiments identified that changes in tail posture and activity level could be indicators of a future tail biting outbreak (Zonderland et al., 2009; Ursinus et al., 2014). In one study, pigs with their tails between their legs had a higher risk of having a tail wound 2–3 days later (Zonderland et al., 2009), and Ursinus et al. (2014)

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observed higher activity levels prior to a tail biting outbreak. These observations are supported by another small study with six tail biting pens, also suggesting that changes in tail posture and activity level might predict a tail biting outbreak (Statham et al., 2009).

So far only a few and minor studies have suggested that changes in behaviour occur prior to a tail biting outbreak either on pig or pen level. If changes in behaviour and tail posture are to be used in a commercial setting as an early warning sign of a tail biting outbreak, it is essential that these can be recognized on pen level. On commercial farms tail biting outbreaks are handled on pen level and individual differences between pigs in a pen will generally not be detected. If changes in behaviour can predict a tail biting outbreak in the early stages at the pen level, pig producers could use this measure in their daily management inspections to identify at risk pens and take steps to reduce tail biting behaviour. In addition, if certain behaviours or tail postures can predict a tail biting outbreak, this opens up the possibility to predict future tail biting outbreaks automatically by the use of sensor or camera technology (Larsen et al., 2016).

The aim of the present study was to investigate whether differences in tail posture and behaviour could be identified at the pen level between pens close to a tail biting outbreak and pens at least seven days away from an outbreak. The study was conducted at a commercial herd with undocked weaner pigs.

2. Material and methods

2.1. Ethical consideration

This experiment was conducted in accordance with the guidelines of the Danish Ministry of Justice, Act No. 382 (June 10, 1987) and Acts 333 (May 19, 1990), 726 (September 9, 1993) and 1016 (December 12, 2001) with respect to animal experimentation and care of animals under study.

2.2. Animals and housing

The study was carried out at a commercial Danish farm from November 2015 to February 2016. The subjects were 2301 undocked DanAvl crossbred ((Landrace × Large White) × Duroc) weaner pigs (7–30 kg) from four different farrowing batches with 55–60 litters per batch and 555–623 pigs per batch. Pigs were born in a loose house farrowing system (for pen design details, see Pedersen et al. (2015)). On day 3 or 4 after birth all the piglets were given iron injections (Uniferon, Pharmacosmos, Holbæk, Denmark), their teeth were ground and male piglets were surgically castrated, (with the use of a short-term analgesia). From approximately 14 days of age piglets were offered solid creep feed on the floor. Two days prior to weaning, pigs were ear tagged and their sexes recorded. At weaning, pigs were 27.7 (SD 2.8) days old and weighed 5.8 (SD 1.5) kg. At this point they were transported to a weaner facility close to the sow unit.

At weaning, pigs were sorted by size within batch and allocated to new pens with 31.1 (SD 1.5) pigs/pen. Recording of gender was missed for some pigs (2.1%). Gender distribution was 49.9% (SD 9.4) castrated males and 48.0% (SD 9.2) gilts per pen. The four experimental rooms consisted of 26 or 30 pens and 18 or 20 of these pens were included in the experiment in each batch. In total 74 pens were included in the study. Pens measured 4.85 × 2.18 m (length × width) with 7.1 m^2 solid floor and 3.5 m^2 cast iron slatted floor. Above the solid floor in the lying area a 2.16 m^2 adjustable covering was placed. Two adjacent pens shared a dry feed dispenser with two nipple drinkers, one placed in each side of the feed dispenser (MaxiMat, Skiold A/S, Sæby, Denmark). In addition, a separate water supply (drinking bowl) was placed next to the feed dispenser towards the slatted floor. Each pen was equipped with two wooden blocks hanging from a chain, not touching the floor. Pens were daily provided with approximately 350 g of finely chopped straw (Easy Strø, Dansk Dyrestimuli, Nykøbing Mors, Denmark) on the solid floor. Artificial lighting was turned on from 0600 h to 2200 h.

The ventilation system was based on negative pressure air flow from wall air inlets in one side of the building (SKOV A/S, Glyngøre, Denmark). At pigs' arrival, the room temperature was 24 °C and it was gradually lowered to 19 °C on day 42. Thermostatically controlled floor heating pipes were placed inside the floor in the lying area giving a floor temperature of 30 °C at the start of the study. The floor heating was turned off on day 14.

Pigs were fed three different commercial compound diets (ad libitum access) from 7 to 30 kg based on wheat, barley, soy protein, fish meal (the last ingredient only from 10 to 15 kg body weight), minerals and vitamins. The diets were formulated to fulfil the nutritive requirements of pigs at this age and genotype. Transition between feed compounds was done gradually over a 7 or 14 days period – depending on the age of the pigs. The age of onset of a diet transition depended on the average body weight in the pen. The experiment continued until a tail biting outbreak occurred in a pen or until the pigs were moved to the finisher barn 6.5 week after weaning.

Pigs' health was monitored once daily in the morning by the stock person, and pigs with clinical signs of disease were treated with antibiotics. Unthrifty animals and pigs with severe tail lesions (more than half the tail missing or swelling as sign of infection) were moved to hospital pens.

If a tail biting outbreak occurred (see definition in 2.3 below) new enrichment materials were added to the pens, and the biter/biters were removed from the pen if they could be identified. The pen left the study at this point, and could not re-enter the study for use as a control pen even though tail wounds had healed. Tail wound healing of tail bitten pigs was followed closely to ensure that damaging tail biting did not continue.

2.3. Tail scoring and tail posture

Of the total number of experimental animals 2259 pigs were tail scored in the farrowing stable and these pigs originated from 222 litters. From right after weaning, tail posture up (curly), down (hanging) or tucked (down and tucked into the body) and tail damage were scored three times weekly (Monday, Wednesday and Friday) until a tail biting outbreak occurred. After a tail biting outbreak, tails were scored once weekly until the end of the study (data not shown). To avoid affecting the tail posture, tail posture was scored from outside the pen before the observer entered each pen to score tail damages. Tail damage was assessed and scored using the scoring system described in Table 1.

2.4. Tail biting outbreak

A tail biting outbreak occurred when at least four pigs in a pen (~13% of the pigs) had a tail damage score of at least a wound. The day of the tail biting outbreak was determined based on the three weekly tail scorings. The daily caretaker did not record any tail biting outbreaks during daily management routines between tail scoring days. We use a numbering convention throughout this paper such that the day of the outbreak is day 0, and the days prior to the outbreak are -1, -2, -3 and so on. Tail biting outbreaks occurred in 70 pens, leaving only four pens without an outbreak in the entire study period (6.5 week).

2.5. Video recordings

An overhead video camera (Dahua 2MP HD IR Dome, Dahua, Haarlemmermeer, Netherlands) was placed above all pens and timed to record from 0700 to 2100 h from weaning until a tail biting outbreak. Due to the poor quality of the video recordings, the first batch (18 pens) had to be excluded from the video material leaving 56 pens for further analysis.

Table 1
Tail injury scoring system.

Tail scoring	Description
Damage severity	
No	No visible tail lesion. Earlier lesion is healed
Minor scratches	Minor superficial scratches
Wound	Visible wound and tissue damage
Wound – tail end will fall of	The outer part of the tail has almost been bitten off. During healing tail tip will fall off
Wound freshness	
Intact scab	The wound is covered with a hard dry scab
Not intact scab	The wound is covered with a scab, but cracks in the scab and dried blood/fresh tissue are visible
Fresh wound – not bleeding (weeping)	Skin is broken, no scab, no blood – only weeping.
Fresh wound – bleeding	Fresh lesion and fresh blood are visible
Tail length	
Intact	Full length tail
Outer part is missing	The outer part of the tail is missing
More than half is missing	More than half of the tail is missing
< 1 cm left of the tail	Less than 1 cm of the tail is left
Swelling	
No	No swelling
Yes	Swollen red tail indicating an infection

2.6. Pilot study

To determine the sampling method for the main study, a pilot study was conducted using videos recordings from 10 pens with tail biting outbreaks. Scan sampling of pig behaviour and tail posture (according to the ethogram in Table 2) were recorded on day -13, -10, -7, -4, -3, -2 and -1 prior to the outbreak (day 0) every half hour from 0700 h to 2100 h to determine if any changes in activity and tail posture could be determined and when the changes could be expected. Visual inspection of pilot study results suggested a change in activity and tail posture within the last three days prior to an outbreak, but not before this (data not shown). Further, these pilot study results showed high activity levels during the morning hours (0800–1100 h) and late afternoon (1700–2000 h; data not shown).

2.7. Behavioural recordings

Behaviour was recorded in pens which would go on to have tail biting in future (T-pens) and, based on pilot observations, pens at least seven days away from an outbreak were used as non-tail biting control pens (C-pens). Based on pilot study observations, it was decided to record pigs' behaviour and tail posture in T-pens and C-pens on day -3, -2 and -1 prior to an outbreak in T- pens to look for changes that could act as early warning of tail biting. Once every half hour pigs' behaviour was recorded using instantaneous scan sampling during the periods of high activity from 0800 to 1100 h and 1700 to 2000 h identified in pilot observations. The ethogram is presented in Table 2.

A tail biting outbreak occurred in 50 of the 56 pens included in the video study. To compare behavioural differences between groups, T-pens and C-pens were randomly paired within batch. Pigs in paired pens originating from the same farrowing batch were analysed on the same dates and were housed in the same room in the weaning period. A pen could feature as both a T-pen and a C-pen depending on the onset of the tail biting outbreak in the pen and the outcome of the random pairing. In order for a pen to be in the pool of available control pens, the pen had to be at least seven days away from a future tail biting outbreak. Based on the random pairing 24 different pens were drawn as C-pens. Therefore, on average a C-pen was paired twice with a T-pen ranging from one to seven pairings per C-pen within batch. If the same pen was picked as a control pen to pens with a tail biting outbreak on the same day, the control pen data only entered the statistical analysis once.

2.8. Statistical analysis

Statistical analyses were performed using SAS Enterprise Guide 7.1 (SAS Institute Inc., Cary, NC, USA) with significance level of $P < 0.05$ and tendency level at $P < 0.10$. Pen was the experimental unit in statistical analyses of behaviour and tail posture.

Table 2
Ethogram for behaviours recorded on video (modified after Zonderland et al., 2011).

Behaviour	Description
Pigs standing or sitting	
Standing/walking	Pigs are standing still or moving around on all four feet.
Sitting	Pigs sitting. Body is supported by hind-quarter and the front legs are straight.
Pigs at feed dispenser	
Nose in trough	Pigs with the nose in the feeding trough.
Head against feeder	Pigs less than one-pig-length away from the trough with the head oriented **towards** the feeder. The head is not in the trough, and pigs are not rooting the floor. It looks like pigs are waiting to get access to the feed.
Head away from feeder	Pigs less than one-pig-length away from the feeder without having the head in the trough. The head is oriented **away** from the feeder.
Nose solid floor feeding	Pigs touching, sniffing, rooting or licking the solid floor within one-pig-length from the feeder.
Pigs at drinking bowl	
Drink or nose the drinking bowl	Pigs with the nose in the drinking bowl or pigs with the head close to the drinking bowl sniffing, touching, rooting or biting the drinking bowl.
Pigs nosing enrichment, floor or pen-mate	
Nose enrichment	Touching, sniffing, rooting or biting the enrichment.
Nose solid floor	Touching, sniffing, rooting or licking the solid floor.
Nose slatted floor	Touching, sniffing, rooting or licking the slatted floor.
Nose tail region/rear end of the pig	Touching, sniffing, rooting, chewing or biting the tail region or immediate surroundings.
Nose pen-mate, body	Touching, sniffing, rooting, chewing or biting other part of the body beside the tail region.
Tail-in-mouth	Chewing, sucking or biting a pen-mate's tail.
Tail posture on standing pigs	
Curly tail	Tail is curly.
Tucked tail/hanging tail	Tail hanging or tucked into the body.
Tail other	Other tail posture not included in the above mentioned, for example sticking straight out.
Tail not shown	Tail posture is not visible.

2.8.1. Video data

The percentage of tails down (sum of hanging and tucked tails), pigs at feed dispenser (sum of all behaviours recorded at the feed dispenser; Table 2), pigs performing explorative behaviour (sum of: nose enrichment + nose solid floor + nose slatted floor; Table 2), pigs performing pen-mate directed behaviour and tail directed behaviour (sum of: tail-in-mouth and nose tail region; Table 2) were calculated as the percentage of standing pigs at each scan. Data on pigs at the drinking bowl were not analysed due to low prevalence. The percentage of standing pigs was calculated as the proportion of pigs in the pen. The overall activity was calculated as the percentage of standing and sitting pigs in the pen.

Behavioural and tail posture differences between T- and C-pens were analysed using the Generalised Linear Mixed Model procedure (GLIMMIX) with group (T-pens vs. C-pens), time of day (morning vs afternoon), day before outbreak (day -1, -2 and -3), days post wean (day 9–17, day 18–26, day 27–35, day 36–45) as fixed effects and pairs of pen (T-pen with C-pen) as a random effect. Interaction was present between group and day with regards to the outcome *percentage of tails down.* All other interactions between group and fixed effects were non-significant in the analyses and these were removed from the models.

2.8.2. Tail damaged pigs and tail posture (video)

Effect of the number of tail damaged pigs on day 0 (pen level categorization: 4–5 injured tails, 6–8 injured tails or > 8 injured tails) on the percentage of tails down based on video observation on day -1, -2 and -3 were analysed using GLIMMIX with injured tails on day 0, day before outbreak and time of day as fixed effects and pen as random effect. Results are presented as mean, ± SE.

2.8.3. Live observations (tail posture)

Tail scoring and live observations of tail posture were performed three times weekly (on Monday, Wednesday and Friday). Therefore, depending on the day of the week of the tail biting outbreak, the previous tail posture recording was carried out either two or three days earlier. Therefore, in the statistical model, tail posture on day -2 and -3 were grouped in one category named day -2/-3. The same categorizing principle was used for day -4/-5 and day -6/-7. Live observations of tail posture were analysed by GLIMMIX with repeated measurements on pen level and number of active pigs and day as fixed effects.

2.8.4. Victim characteristic, weight categorization and litter origin

Pigs which were scored with a tail wound or scratch at least once after weaning were characterized as a victim (binary variable). Pigs within pen were categorized into four weight groups (25 percentiles) according to weaning weight. The risk of becoming a tail biting victim was analysed using GLIMMIX with sex, victim at weaning, litter origin and weaning weight category as fixed effects. Pen and batch was included as random effects. Correlation between average weaning weight (mean) at the pen level and the onset of a tail biting outbreak (days post wean) was analysed using the correlation procedure (Proc CORR).

3. Results

Tail biting outbreaks occurred in 70 of the 74 pens. On the day of the tail biting outbreak (day 0), on average 7.6 (SD 4.3; range 4–27 pigs/pen) pigs in T-pens had tail damage (scratch and wound). The distribution of tail scores at weaning and on day 0 is listed in Table 3. At weaning 5.7% of the pigs still with a full-length tail (no parts of the tail were bitten off) were scored with tail damage (scratch and wound), whereas on day 0 (tail biting outbreak day) 23.8% had a wound or a scratch. On the day of the tail biting outbreak (day 0) most of the damaged tails were still full length (1.8% had lost the outer part of the tail). On average, tail biting outbreaks occurred 26.6 days after weaning (SD 11.0, range: 9–49 days) in T-pens.

Table 3
Tail damage frequency and distribution (%), broken down by damage to intact tails, and damage when part of the tail is missing at weaning and on the tail biting outbreak day (day 0).

Tail score	At weaning(farrowing stable)		Tail biting outbreak (day 0)	
	No.	%	No.	%
No tail injury	2131	94.3	1706	76.2
Intact length and…				
Scratches, intact scab	69	3.1	15	0.7
Scratches, scab not intact			17	0.8
Wound, intact scab	57	2.5	311	13.9
Wound, scab not intact			90	4.0
Fresh wound, not bleeding			21	0.9
Fresh wound, bleeding	2	0.1	38	1.7
Outer part of tail is missing and…				
Wound, intact scab			18	0.8
Wound, scab not intact			7	0.3
Fresh wound, not bleeding			5	0.2
Fresh wound, bleeding			6	0.3
Intact, outer part of tail will fall off			5	0.2
Total[a]	2259	100	2239	100

[a] Some pigs were moved to hospital pens or died between the tail scoring at weaning and day 0.

3.1. Changes in behaviour prior to an outbreak (Video)

The percentage of tails down (sum of: hanging and tucked tails) and the percentage of active pigs recorded in T- and C-pen are presented in Fig. 1. More tails were down in T-pen than in C-pens ($P < 0.001$). This variable was affected by the interaction between group and day before outbreak with more tails down on day -1 than on day -2 and day -3 in T-pens, and more tails down on day -1 than on day -2 in C-pens ($P < 0.05$), but there was no difference between C-pens on day -1 and -3 or between day -2 and -3. There was no difference between groups (T- vs C-pens) and days in percentage of active pigs (Fig. 1).

Results from video recordings of pigs at the feeder, pigs nosing floor/enrichment, pigs nosing body of pen mates or pigs engaged in tail directed behaviour are presented in Table 4. Day before outbreak did not significantly influence any of the recorded behaviours, but there tended to be more tail directed behaviour in T-pens ($P = 0.06$).

Fig. 2 shows the association between tail posture on day -1, -2, -3 and tail damaged pigs on day 0. On day -1 more tails were hanging in pens with more severe tail-biting outbreaks with 6–8 and > 8 tail damaged pigs compared to outbreak pens with 4–5 tail damaged pigs on day 0 ($P < 0.001$). No difference in tail posture between these different groups was observed on day -2 and -3. In addition, more tails were hanging on day -1 than on day -2 and -3 in pens with 6–8 and > 8 tail damaged pigs ($P < 0.001$). No difference in tail posture was observed between days in pens with 4–5 tail damaged pigs on day 0.

3.2. Morning vs. afternoon

More pigs were active (40.0% vs 34.8%, ± 0.78 (SE), $P < 0.001$), more pigs were at the feeder (18.1% vs 15.1%, ± 0.26, $P < 0.001$) and more pigs performed explorative behaviour (30.6% vs 27.9%, ± 0.65, $P < 0.001$) in the afternoon/evening than in the late morning. Pen-mate (4.2% vs 4.0%, ± 0.13, $P = 0.70$) and tail directed behaviour (0.9% vs 1.0%, ± 0.11, $P = 0.28$) did not differ between morning and afternoon recordings.

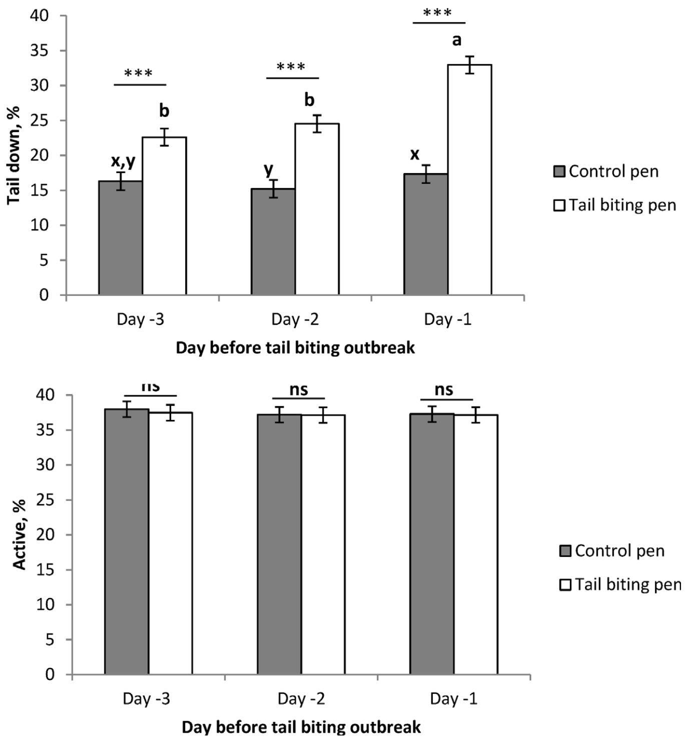

Fig. 1. Percentage of hanging tails and percentage of active pigs in T-pens and C-pens on Day -3, Day -2 and Day -1 before a tail biting outbreak (14 half-hourly scan samples 0800–1100 h and 1700–2000 h on video). Data is presented as LSmeans (± SE).
Different superscript *a* and *b* represent significant differences of P < 0.05 between day in T-pens. *X* and *y* represent significant differences of P < 0.05 between days in C-pens.
*** = P < 0.001 and ns (non-significant) represent differences within day between C-pens and T-pens.

Table 4
Percentage of pigs at the feeder and percentage of pigs engaged in explorative behaviour, pen-mate directed behaviour and tail directed behaviour on day -3 (d -3), -2 (d -2) and -1(d -1) prior to a tail biting outbreak in T-pens and C-pens.

	T-pens			C-pens			SE	P- value	
	d -3	d -2	d -1	d -3	d -2	d -1		Group	Day
Pigs at feed dispenser, %	16.5	16.5	16.1	17.1	16.8	17.0	0.4	0.16	0.75
Explorative behaviour, %	29.8	29.3	28.4	29.6	29.1	29.3	0.95	0.86	0.52
Pen-mate directed behaviour, %	4.2	4.0	4.3	3.8	3.9	4.1	0.34	0.53	0.65
Tail directed behaviour, %	0.88	1.2	1.16	0.91	0.73	0.91	0.11	0.06	0.54

3.3. Changes in tail posture in T-pens (live observations)

Similar to the findings for the video observations, live observations of tail posture showed that there were more tails down on the day of the outbreak (day 0) compared to the days before the outbreak -2/-3, -4/-5 and -6/-7 ($P < 0.05$; Fig. 3) in T-pens.

3.4. Effect of weaning weight

No correlation was observed between the average weaning weight on the pen level and the time of onset (days post wean) of a tail biting outbreak ($R = 0.03$, $N = 70$, $P = 0.8$).

3.5. Victims

From weaning until the day of the tail biting outbreak, 650 different pigs were observed with a tail wound/scratch. No difference between the sexes were found in the risk of becoming a tail biting victim ($F_{1,2094} = 2.51$; $P = 0.11$). There was a strong tendency that weaning weight had an influence on the risk of becoming a tail biting victim ($F_{3,2091} = 2.50$; $P = 0.06$). The largest pigs (Top 25th percentile) in a pen tended to be scored more often with tail damage than the smallest pigs.

Pigs originated from 222 different litters in the farrowing stable. Pigs with a scratch or tail wound originated from 88 different litters (128 pigs: range 1–4 pigs per litter) and pigs with a tail wound originated from 47 litters (59 pigs, range: 1–3 pigs per litter). The chance of becoming a victim in the weaner period was not affected by litter origin in the farrowing unit ($F_{220,1941} = 0.87$, $P = 0.91$). Further, the results showed that pigs with a tail injury at weaning might be at a higher risk of becoming a tail biting victim compared to pigs without a tail injury at weaning ($F_{1,2096} = 3.4$, $P = 0.07$).

4. Discussion

We investigated whether a future tail biting outbreak could be predicted at the pen level based on behavioural changes on day -3, -2 and -1 before an outbreak (day 0). The results showed more hanging tails in future tail biting pens (T-pens) than in non-tail biting pens (C-pens) on the three recording days. The percentage of pigs with their tails down almost doubled in number (based on video recordings) in pens close to a tail biting outbreak compared to control pens. Direct observations of tail posture displayed the same trend, with more hanging tails in tail biting pens on the day of the tail biting outbreak compared to earlier. The large increase in tails down on the pen level could make the measure applicable for use in commercial farms. On average, it was estimated that direct recordings of tail posture took

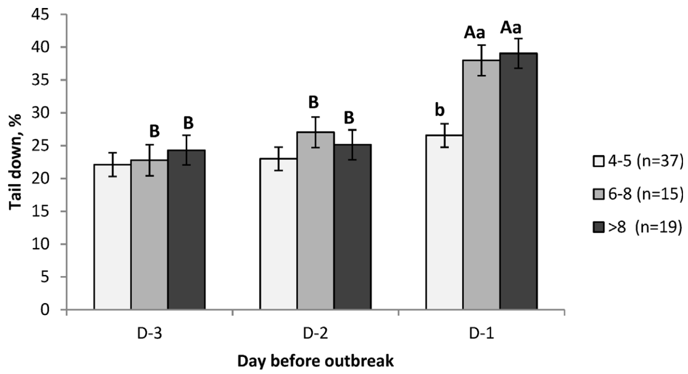

Fig. 2. Percentage of tails down on day -3, -2 and -1 according to number of tail damaged pigs on day 0. Pens were classified into three groups; 4–5 (37 pens), 6–8 (15 pens) or > 8 (19 pens) tail damaged pigs on day 0. Different small letters a and b indicates significant difference of $P < 0.001$ between pens within day. Different capital letters A and B indicates significant difference between days within group.

approximately 1–2 min per pen. Using tail posture changes, as a measure of a future tail biting outbreak, might give farmers a tool to detect the outbreak in its early stages, stop the damaging behaviour and thereby avoid more severe tail damage.

Results from video recordings in tail biting pens reported 33% tails down on the day before the outbreak (day -1). This was higher than on day -2 and -3. Live observations of tail posture in tail biting pens showed the same increase in tails down from day -3/-2 to day 0 with an increase from 17% to 30% hanging tails. The resemblance between tails down on day 0 (live observation) and day -1 (video observation) is supported by Larsen et al. (2016), who suggests that the change in tail posture from curly to hanging prior to an outbreak occurs, because pigs experience pain in the tail even in the pre-injury stages of tail directed behaviour. The hypothesis that tail posture predicts tail biting is further supported by findings reporting that individual pigs with the tail down and no tail damage had a higher chance of having a tail wound 2–3 days later (Zonderland et al., 2009). The lowered tail might be the pigs attempt to protect the tail and avoid further biting.

Previous studies have shown a correlation between activity and tail biting with higher activity in tail biting pens (Statham et al., 2009; Ursinus et al., 2014). Our results do not support these findings, but the differences between studies could have a number of causes. In the study by Statham et al. (2009), the increase in activity prior to an outbreak was only observed in pens with severe outbreaks. A severe outbreak occurred when blood was visible and at least two pigs had severe tail damage (partially tail loss). This may indicate that changes in activity are useful to detect full blown tail biting outbreaks and not as an early warning sign of an imminent outbreak. The finding is further supported by the fact that within tail biting pens no changes in activity level occurred from day -3 to day -1 in the present study. However, other reasons could also explain the differences between our results and previous studies (Statham et al., 2009; Ursinus et al., 2014). First, our study was conducted on weaners, whereas Ursinus et al. (2014) and Statham et al. (2009) observed changes in activity prior to an outbreak in finishers. Second, we recorded activity as the percentage of standing and sitting pigs, whereas in the other two cited studies active lying or sitting pigs were included in the activity measure. We only included standing/sitting pigs in the activity measure, because we wanted a measure of activity that the stock person could implement in their daily management routine. A third reason for the difference between above mentioned studies, could be due to when the activity was recorded. We recorded activity in the late morning and in the late afternoon/evening, and as in other studies pigs did get more active in the afternoon (Costa et al., 2013; Lahrmann et al., 2014). It is possible that differences in activity between tail biting pens and control pens would have been more pronounced during the daily resting periods. One study reported that tail biting behaviour increased the restlessness of the pigs (Zonderland et al., 2011). This restlessness might be more difficult to detect in periods of the day, where pigs are normally active according to their diurnal activity rhythm.

In accordance with previous studies, no differences in explorative behaviour towards the floor or pen-mates were observed between tail biting pens and control pens (Statham et al., 2009; Ursinus et al., 2014). In addition, the percentage of pigs at the feeder did not differ either, this is in agreement with Wallenbeck and Keeling (2013).

Our results showed an increasing percentage of tails down with an increasing number of tail damaged pigs. This further supports the correlation between tail posture and tail biting. Similarly, Zonderland et al. (2009) reported on pig level that pigs with a hanging/tucked tail on the day of the tail biting outbreak had to a larger extent a tail wound

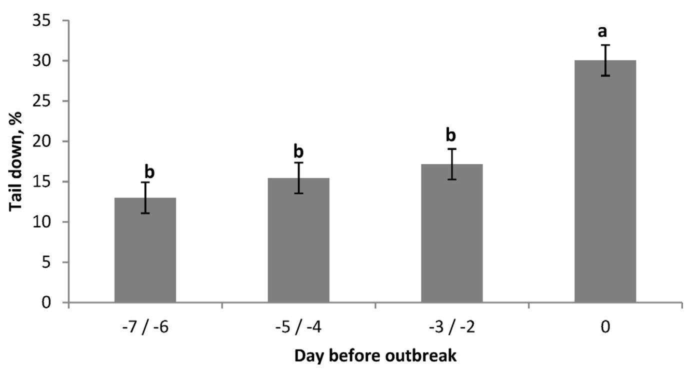

Fig. 3. Percentage of tails down assessed by a live observation (pen-side) on day -7/-6, -5/-4 and -3/-2 before a tail biting outbreak and on the day of the tail biting outbreak (day 0). Different superscript (a, b) represent significant difference of $P < 0.05$.

compared to pigs with a curly tail.

In control pens on average 15–17% of the tails were down. These numbers indicate that hanging tails are not always damaged. Based on experience gained from the data collection, it may be speculated that tail posture is influenced by the activities of the pigs. By watching the pigs, it was our impression that pigs rooting the floor were more likely to have a tail hanging down compared to pigs walking around. It also seemed as if tails were often down when pigs stopped after running around, and then after a short while, tails curled up again if not damaged. Tail posture according to pig behaviour was not recorded in the present study, and further research is needed to understand how different activities affect tail posture.

Tail damaged pigs were observed in 88 litters (2.6% wounds and 3.1% bite-marks) in the farrowing unit just before weaning. For comparison, 9.2% of the pigs had tail wounds and 36.9% had bite marks at weaning in a Dutch experiment with undocked pigs (Ursinus et al., 2014). A tendency was found, that tail biting victims at weaning had a higher risk of becoming a tail biting victim later in the weaning period. This is in contrast with the study by Ursinus et al. (2014), who found no such correlation. Overall these results indicate that it is not likely that future tail biting victims can be predicted based on tail damage in the pre-weaning period.

The largest pigs in a pen (25 percentile) were more often victims than the smallest ones (25 percentile), which is in accordance with some previous findings (Van de Weerd et al., 2005; Zonderland et al., 2011), but in contrast with Munsterhjelm et al. (2016), who did not find this difference. Taylor et al. (2010) suggested that the heaviest pigs are often the first to eat in the active periods, which might make them more exposed to the tail biting behaviour from other hungry and perhaps restless pigs.

In the present study, we found no difference in sex between victims. As discussed by Lahrmann et al. (2017) inconsistencies between studies exist, when the risk of becoming a victim is assessed based on sex.

The present study was conducted under commercial conditions in one herd, but the authors believe that changes in tail posture could be an indicator of a future tail biting outbreak regardless the housing environment. We believe so, as it is probably the victims' reaction to pain in the tail that triggers the change in tail posture from curly to hanging/tucked as discussed by Larsen et al. (2016).

5. Conclusion

Percentage of hanging tails was almost doubled in pens close to a tail biting outbreak (day -1), compared to pens seven days or more away from an outbreak. In pens close to an outbreak more tails were hanging on day -1 than on day -2 and day -3. These tail posture changes, based on video observations, were supported by live observation of tail posture showing almost the same increase in percentage of hanging tails from day -3/-2 to day 0. In addition, results showed that in outbreak pens with a higher number of pigs with a tail wound on day 0 there were more hanging tails on day -1. Changes in activity level, explorative behaviour or pen-mate directed behaviour were not evident prior to an outbreak. In conclusion, our results indicate that lowered tails could be a promising and practical measure to detect the damaging tail biting behaviour at the pen level before the behaviour causes severe tail damage.

Conflict of interest

The authors declare no conflicts of interest.

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9.3 Paper III

Lahrmann, H.P.[1,*], Hansen, C.F.[1], D'Eath, R.B.[2], Busch, M.E.[1,5], Nielsen, J.P.[3], Forkman, B.[4]
Early intervention with enrichment can prevent tail biting outbreaks in weaner pigs. 2018. Livestock Science 214, 272-277.

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Early intervention with enrichment can prevent tail biting outbreaks in weaner pigs

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ABSTRACT

Tail biting is a serious animal welfare problem in the modern pig production. A frequently studied preventive measure is enrichment materials, and increasing levels of enrichment materials, especially litter materials, reduces the risk of tail biting. However, permanent access to litter materials, can cause blockage of the slurry system and increase production cost. The aim of the present study was, therefore, to investigate if providing extra enrichment material, when observing the first tail damage could reduce the prevalence of tail biting outbreaks. The study included 1804 weaner pigs from 7 to 30 kg distributed in 60 pens with intact tails. As basic enrichment material, pens were equipped with two wooden sticks and daily provided with approximately 400 g of fine chopped straw. From outside the pen pigs were checked for tail damages three times weekly. When the first tail damage (fresh or scabbed) was recorded, the pen was assigned to one of four treatments; chopped straw (approximately 200 g/pen) on the floor (straw), haylage in a spherical cage (haylage), hanging rope with a sweet block (rope) or no extra material (control). From first treatment day and until a tail biting outbreak, tails were scored three times weekly. A tail biting outbreak occurred when four pigs in a pen had a tail damage, irrespective of wound freshness. The experiment was designed to compare the prevalence of tail biting outbreaks in each of the extra material group with the control group. A treatment was carried out in 44 of the 60 pens: 10 pens with straw, 8 pens with haylage, 7 pens with rope and 19 control pens. The risk of a tail biting outbreak was significantly lower in pens with haylage and straw compared with control pens ($P < 0.05$), and there tended to be fewer tail biting outbreaks in rope-pens compared with control pens ($P = 0.08$). The results should, though, be interpreted with caution due to the relatively small sample size. In control pens with no intervention, a tail biting outbreak developed in 42% of the pens within two to five days after the first tail damage was observed, whereas a tail biting outbreak did not occur in 32% of the control pens. In conclusion, a regular tail inspection and the use of extra enrichment material, when the first minor tail damage occur, could be one way to reduce the prevalence of tail biting outbreaks.

1. Introduction

Tail biting is a major animal welfare and economic problem, which remains prevalent in modern pig production (D'Eath et al., 2016). To prevent or reduce the level of tail biting, a series of different actions have been implemented. One of the most common preventive measures is tail docking which decreases the risk of tail biting (Lahrmann et al., 2017; Larsen et al., 2017). Tail docking is, however, a controversial solution to the problem since there is ample evidence that the tail docking procedure itself is painful (Herskin et al., 2016), and since the long-term effect is less well documented (Di Giminiani et al., 2017). Although routine tail docking is prohibited in the EU, it is still common (D'Eath et al., 2016). The European Commission is working to decrease the number of tail docked pigs and subsequently has published guidelines to member states on how to reduce routine tail docking by improving housing systems and management routines (EC, 2016). Because of the welfare issue and increased focus on ceasing routine tail docking, it is essential to find alternative solutions to the tail biting problem.

An additional reason for reducing the use of tail docking is that it does not eliminate the underlying problems causing the tail biting

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behaviour (Sutherland and Tucker, 2011). Although the causation of tail biting is multifactorial and may include insufficient feeding space, poor nutrition, poor health etc. (D'Eath et al., 2014), a large proportion of studies on tail biting have investigated the effect of permanent access to loose enrichment materials in the prevention of tail biting outbreaks (e.g. straw Zonderland et al., 2008; compost Beattie et al., 2001; alfalfa hay and corn silage Veit et al., 2016). These studies have been conducted as lack of enrichment materials, which increase the risk of tail biting (Schrøder-Petersen and Simonsen, 2001; Taylor et al., 2010). Permanent access to litter materials such as compost and straw, however, has a number of disadvantages for the farmers and will increase production costs due to extra labour and material expenditures (Tuyttens, 2005). A recent survey of Swedish farmers also found that concerns about the perceived inability of the manure system to handle large amounts of straw was the main reason for not using more of it (Wallgren et al., 2016). An alternative may therefore be to give access to a material that does not block the manure system to the same extent as straw, e.g. rope or hay in a rack (D'Eath et al., 2014).

However, even these alternatives may be costly or labour intensive. Another approach could therefore be to give the more-costly, but more attractive, materials only when needed to prevent tail biting. An attractive material, was in a review dealing with pigs' motivation to explore, defined as 'edible', 'changeable', 'destructible' and 'manipulable' (Studnitz et al., 2007). While only providing extra materials in pens where the first minor tail damage is detected may be less preferable than continuous access to the material, it has the advantage of being less costly/manageable for the farmer to handle and therefore may be more likely implemented.

Until recently, tail biting outbreaks have been notoriously difficult to predict. Recent studies have, however, demonstrated that tail postures change from curly to hanging prior to a tail biting outbreak (Zonderland et al., 2009; Lahrmann et al., 2018). Lahrmann et al. (2018), found that the change in tail posture was so pronounced that it would be possible for a farmer to use in daily health monitoring.

To our knowledge, only one previous study has examined the effect of different interventions on tail damaged pigs in pens with a tail biting outbreak (removing the biting pig or giving straw - Zonderland et al., 2008). No previous studies have examined provision of extra enrichment material as an early intervention, just when the first minor tail damage is observed, to determine if this can reduce the tail biting behaviour and thereby prevent tail biting outbreaks. The aim of the current experiment was to investigate whether early interventions could prevent tail biting outbreaks in weaner pigs. It was hypothesized that providing straw, haylage in a spherical cage or sisal rope, when the first pig in a pen was observed with a tail damage, would reduce the occurrence of subsequent tail biting outbreaks. Further, we wanted to establish whether less than four weaners (< 14 percentage of the pigs/pen) with a tail injury was a sign of an upcoming tail biting outbreak within the next two to five days. Finally, we scored tail posture as well as tail injury to establish the relationship between these in the early stages of tail biting outbreaks.

2. Material and methods

Before the study, the Animal Experiments Inspectorate evaluated the research protocol and decided that the study could be conducted in accordance with the guidelines of the Danish Ministry of Justice Act no. 382 (June 10,1987) and Act no. 333 (May 19, 1990), 726 (September 9, 1993) and 1016 (December 12, 2001) with respect to animal experimentation and care of animals under study.

2.1. Experimental design, animals and housing

The study was carried out at a commercial Danish farm from November 2016 to February 2017. The experimental design included four treatments differing in type of enrichment material: straw on the floor (straw), haylage in a ball of metal mesh (haylage), sisal rope with a sweet-tasting block (rope) and control treatment (no intervention). To comply with Danish legislation on permanent access to manipulable and rooting materials, each pen was equipped with two wooden sticks hanging in a chain as manipulable material and dry feed in a dispenser as rooting material.

The experiment was designed to compare the prevalence of tail biting outbreaks in control pens with each treatment where extra enrichment material was added to the pen. The number of control pens was therefore double the number of treatment pens. The treatments were initiated at pen level when at least one pig in a pen was observed with a tail wound. The sequence of the four treatments was randomized at the start of the experiment, and then followed the same order.

The subjects were 1,804 undocked DanAvl crossbred ((Landrace x Large White) x Duroc) weaner pigs (7–30 kg) from three farrowing batches with 590–617 pigs per batch. Pigs were born in a loose house farrowing system (for pen design see, Pedersen et al., 2015). Iron injections (Uniferon, Pharmacosmos, Holbæk, Denmark), grinding of the tip of the needle teeth (Tandsliber proff, Hatting, Horsens, Denmark) and surgical castration of male piglets took place on day three or four after birth. Male piglets were given analgesic just before castration (Melovem® 5 mg/ml).

From the piglets were about 14 days old they were offered solid creep feed on the floor. Piglets had access to the straw that the sow pulled from a straw rack. Two days prior to weaning, piglets were ear tagged and their sex noted. According to the piggery's production report, the lactation period was 28.4 days. At this point the pigs were transported to a weaner facility close to the sow unit.

The weaner facility consisted of eight rooms of which three were used in the experiment. Each room had 26 or 30 pens evenly distributed on each side of an inspection aisle, and 20 or 21 pens in each unit were included in the experiment. A total of 60 pens were included in the study. Pens measured 4.85 × 2.18 m (length × width) with 7.1 m^2 solid floor towards the wall and 3.5 m^2 cast iron slatted floor towards the aisle. A 2.16 m^2 adjustable covering was placed above the lying area of the solid floor. Two adjacent pens shared a dry feed dispenser with two nipple drinkers (MaxiMat, Skiold A/S, Sæby, Denmark). In addition, a drinking bowl was placed next to the feed dispenser. Each pen was equipped with two wooden blocks hanging in a chain just above the floor, but without touching the floor. Pens were daily provided with approximately 400 g (one scoop) of fine chopped straw (Easy Strø, Dansk Dyrestimuli, Nykøbing Mors, Denmark) on the solid floor irrespective of treatment.

The ventilation system was based on negative pressure air flow from wall air inlets in one side of the building (SKOV A/S, Glyngøre, Denmark). At piglets' arrival, the room temperature was 24 °C which was gradually lowered to 19 °C on day 42. Thermostatically controlled floor heating pipes in the lying area led to a floor temperature on arrival of 30 °C, which was turned off 14 days later.

Upon arrival at the weaner facility, pigs within batch were sorted by size with 29.6 (SD 0.56) pigs per pen with an average gender distribution within pen of 51% castrated males and 49% gilts (minimum-maximum: 31 − 69% castrated males). Three different home-mixed compound diets (ad libitum access) were provided from 7 to 30 kg. The diets were formulated to fulfil the nutritional requirements of pigs of this age and genotype. Phase one diet allocated from 6–10 kg (19.4% crude protein) consisted of 55.0% wheat, 22.0% Danstart 225 Vilomix (Vilomix, Mørke, Denmark), 10.0% barley, 9.0% fish meal and 4.0% soy oil. Phase two diet allocated from 10–15 kg (18.2% crude protein) consisted of 48.0% wheat, 25.0% barley, 14.7% toasted soy bean, 6.8% premix of mineral and vitamins (MIN 27600, Vilomix, Mørke, Denmark), 3.0% fish meal and 2.5% soy oil. Phase three diet allocated from 15–30 kg (19.0% crude protein) consisted of 48.8% wheat, 24.5% toasted soy bean, 20.0% barley, 4.5% premix of mineral and vitamins (MIN 27603, Vilomix, Mørke, Denmark) and 2.2% soy oil. Shifts in diets

Table 1
Tail posture and tail damage.

Tail posture/ tail damage	Description
Tail posture	
Curly	Tail is up and curly
Hanging	Tail is down and hanging relaxed alongside the rear end of the pig
Tucked	Tail is down and pressed against the rear end of the pig
Hanging tails – tail condition[a]	
Intact tail	Hanging tail with no visible change in colour as a sign of a tail wound
Scabbed wound on tail end	The tail end is black and covered with a scabbed wound
Bleeding tails	
Bleeding wound	Tails with a fresh wound irrespective of tail posture

[a] Tail condition was only scored on hanging tails. Scoring the tail condition (wound or not) on tucked tails from outside the pen was not possible.

were gradually carried out over a 7 or 14 days period, depending on the age of the pigs. The onset of a diet shift depended on the average body weight of pigs in the pen.

A stock person monitored the pigs' health once a day in the morning, and, when needed according to the herd veterinarian recommendations, pigs with clinical signs of disease were treated with antibiotics. Unthrifty animals and pigs with severe tail lesions (more than half the tail missing or swelling as sign of infection) were moved to hospital pens.

2.2. Tail posture at pen level

Three times weekly (Monday, Wednesday and Friday), the number of standing pigs, tail posture and tail damage were recorded from outside the pen according to Table 1 until at least one pig were observed with a tail wound. Before recording tail posture, the observer went into the pen, got every pig up, walked outside the pen and did the recordings.

2.3. Clinical examination of tails at individual tail scoring

When one pig with either a scabbed wound on a hanging tail, a tucked tail or a fresh wound irrespective of tail posture was observed, all pigs in the pen were tail scored according to the scoring system presented in Lahrmann et al. (2018) (Table 2). A wound was defined as a clear puncture of the skin with tissue damage as in Lahrmann et al. (2018) with a severity of at least a 'wound' (Table 2). After tail scoring one of the four treatments, based on a random predetermined order, was allocated to the pen. From the day of the early intervention and until a tail biting outbreak, tails were scored three times weekly. A tail biting outbreak was defined as four pigs with a tail wound irrespective of tail length and wound freshness. The pen left the study if a tail biting outbreak occurred, and extra enrichment material, beyond what was used as treatments, was added to stop the tail biting behaviour.

If a pig was continuously observed chewing/biting the tail of the pen mates during formal inspection, it was removed from the pen and the pen left the study.

2.4. Treatments

When one pig (day 0) was observed with a damaged tail or a tucked tail during the three weekly tail scorings, one of four treatments was randomly allocated to the pen; straw, haylage, rope or control (no intervention).

In pens with straw treatment from day 0, approximately 200 g of chopped wheat straw (cut during harvest in the combine harvester) were provided daily during the morning hours on the solid floor (approximately 7 g per pig per day).

Table 2
Tail injury scoring system used in the present study and in Lahrmann et al. (2018).

Tail scoring	Description
Damage severity	
No	No visible tail lesions. Earlier lesion is healed
Minor scratches	Minor superficial scratches
Wound	Visible wound and tissue damage
Wound – tail end will fall of	The outer part of the tail has almost been bitten off. During healing tail tip will fall off
Wound freshness	
Intact scab	The wound is covered with a hard-dry scab
Not intact scab	The wound is covered with a scab, but cracks in the scab and dried blood/ fresh tissue are visible
Fresh wound – weeping	Skin is broken, no scab, no blood – only weeping
Fresh wound – bleeding	Fresh lesion and fresh blood are visible
Tail length	
Intact	Full length tail
Outer part is missing	The outer part of the tail is missing
More than half is missing	More than half of the tail is missing
< 1 cm left of the tail	Less than 1 cm of the tail is left
Swelling	
No	No swelling
Yes	Swollen red tail indicating an infection

In the haylage treatment from day 0, ryegrass haylage was provided in a spherical cage with a diameter of 30 cm (https://heuballferkel.jimdo.com/) made of metal bars hanging in the middle of the pen above the solid floor approximately one meter from the slatted floor. The ball was placed at a height enabling pigs to pull out material from the bottom, and it was gradually lifted as pigs grew. The spherical cage was refilled once daily with approximately 650 g of haylage, and no material was left in the cage the following day.

In the rope treatment, sisal rope (diameter; 20 mm) with a sweet block hung in the same location as the spherical cage. The 650 g sweet-tasting block with apple flavour (Likit™, www.likit.co.uk/treats-toys/horse-licks/) was placed on the rope at pig head level. According to the manufacturer, the Likit™ block was composed of glucose syrup, dextrose, ground safflower seed and blue-green algae extract. Rope was pulled through the block leaving 30 cm of rope lying on the floor. To keep the block in place, two round wooden discs were placed beneath and above the block and a knot was tied on the rope on each side of the wooden discs. A coil of rope hung above the pen, and every second day, if no rope was lying on the floor, new rope was pulled from the coil leaving 30 cm on the floor. If pigs consumed the Likit block, a new block was placed on the rope once. If the block was consumed again, no new block was added, but rope was still renewed as described.

In control pens, no new or additional material was provided on the day, when at least one pig in a pen was observed with a tail wound (day 0).

Of the 60 pens included in the study, an early intervention was performed in 44 pens. In these 44 pens, one of four treatments were provided: Straw on floor (10 pens), haylage in a spherical cage (8 pens), rope with a sweet block (7 pens) or no extra material (control, 19 pens). Pens with a tail biting outbreak on the intervention day were not evenly distributed between treatments, giving the inequality in number of pens provided with straw, haylage or rope. The extra material was provided until the pen left the study, either due to a tail biting outbreak (four pigs with a tail wound) or because pigs were moved to the finisher location at approximately 30 kg live weight after 6.5 weeks.

2.5. Statistical analysis

Statistical analyses were performed in SAS Enterprise Guide 7.1 (SAS Institute Inc., Cary, NC, USA) using Generalised Linear Mixed

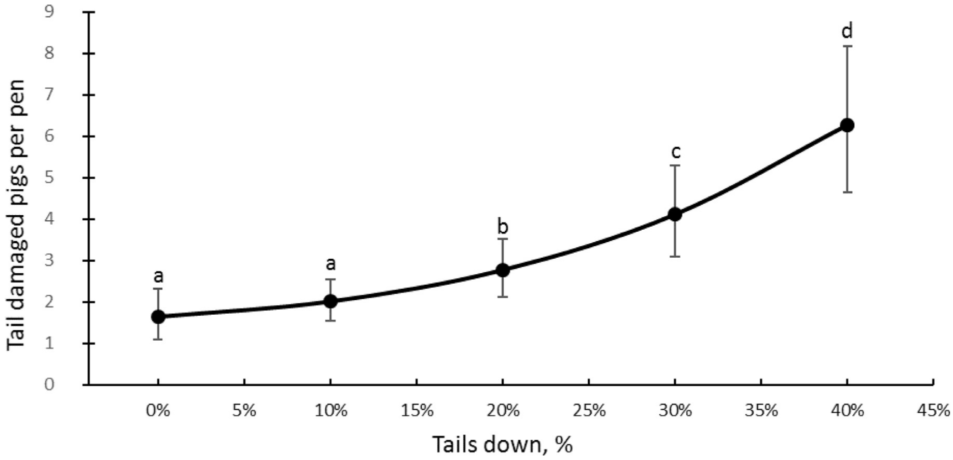

Fig. 1. Plot of the percentage of tails down (back-transformed least square means) against the average number of tail damaged pigs per pen within the first ten days after intervention (n = 255). Different superscripts indicate significant difference of $P < 0.001$.

Model procedure (GLIMMIX) with a significance level of $P < 0.05$ and pen as the experimental unit.

In the statistical model analysing for differences in prevalence of tail biting outbreaks (binomial distribution) the control group was compared to each treatment (straw, haylage or rope). Treatment and age at intervention were included as fixed effects and batch as random term.

At pen level, the correlation between percentage of hanging tails and tail damaged pigs recorded on the same day at the first five recordings after the intervention day (day 0) was analysed using GLIMMIX. To ensure homogeneity of variance, the variable number of tail damaged tails was square root transformed. Recording day after intervention and age at intervention were included as systematic effects, whereas pen was included as a random effect. Data presenting the correlation between hanging tails and tail damage had the best fit to a curve based on quadratic equation. The correlation between numbers of tail damaged pigs in pens with 0, 10, 20, 30 and 40 percentage hanging tails was estimated and is presented in Fig. 1. Results are presented as back-transformed least square means including 95% confidence limits.

3. Results

In total 44 out of the 60 pens entering the study was included in the analysis. In two pens, no tail injured pigs were observed through the study period. The distribution of tail scores on the day of the early intervention is listed in Table 3. In 14 pens, there was a tail biting outbreak (four or more pigs with a tail damage) on the intervention day, and an early intervention could therefore not be conducted in these pens. In the 44 pens with an early intervention, 1.7 pigs per pen (SD 0.74, range 1–3 pigs) had a tail damage on the day of the intervention. The first tail damaged pig in a pen was observed on average 13 days (SD 10.2, range 2–42 days) after weaning. During the experimental period from 7 to 30 kg, no pigs had to be removed to a hospital pen due to tail biting. In pens with a tail biting outbreak, the biting behaviour was ceased either by giving extra enrichment material or by removing the biting pig. A biter was removed from one control pen ten days after the first pig was observed with tail damage. No pigs, neither victims nor biters, had to be removed due to tail damage in pens with an early intervention.

3.1. Early intervention and tail biting outbreaks

A tail biting outbreak developed in one pen with haylage, in two rope pens and two straw pens (five pens in total), Table 4. The risk of a tail biting outbreak was significantly lower in pens with haylage and straw compared with control pens ($P < 0.05$). There tended to be fewer tail biting outbreaks in rope pens compared with control pens ($P = 0.08$).

In total, a tail biting outbreak developed in 18 pens (Table 5), and in 62% of the control pens with outbreaks, the outbreak developed within two to five days after the first pig/pigs with tail wounds were recorded.

Table 3
Tail damage frequency and distribution (%), broken down by damage to intact tails, and damage when part of the tail is missing on day 0 (day of early intervention) in 58 pens.

Tail score	Early intervention day	
	No.	%
No tail injury	1534	89.4
Intact length and…		
Scratches, intact scab	10	0.6
Scratches, scab not intact	1	0.06
Scratches, fresh/ bleeding	5	0.3
Wound, intact scab	109	6.4
Wound, scab not intact	12	0.7
Fresh wound, not bleeding	5	0.3
Fresh wound, bleeding	38	2.2
Outer part of tail is missing and…		
Wound, intact scab	0	0
Wound, scab not intact	1	0.06
Fresh wound, not bleeding	1	0.06
Fresh wound, bleeding	0	0
Intact, outer part of tail will fall off	0	0
Total[a]	1716	100

[a] Some pigs were moved to hospital pens or euthanized between weaning and day 0.

3.2. Tail posture and tail damage

At pen level, the number of pigs with tail damage was positively correlated with the number of pigs with a hanging tails ($F_{1,195} = 7.97$; $P < 0.01$) (Fig. 1). Significantly more pigs had a damaged tail in pens with 20, 30 and 40% hanging tails compared with pens with 0% and 10% hanging tails.

Table 4
The number of pens with an early intervention, the number of pens with a tail biting outbreak and the average number of tail damaged pigs per pen on the intervention day (day 0) and on the day of the tail biting outbreak (SE).

	Intervention				*P*-value		
	Control	Straw	Haylage	Rope	C × S	C × H	C × R
Number of pens, n	19	10	8	7	–	–	–
Tail damaged pigs, day 0	1.7 (0.73)	1.5 (0.71)	1.4 (0.52)	2.1 (0.9)	0.22	0.45	0.46
Pens with tail biting outbreak, *n*	13	2	1	2	–	–	–
Pens with tail biting outbreak, % of pens[a]	73 (18.3)	15 (14.6)	8.9 (10.9)	28 (23.8)	< 0.05	< 0.05	0.08
Tail damaged pigs per pen on the day of the outbreak, n	7.4 (6.0)	15.5 (14.9)	4.0	4.5 (0.7)	–	–	–

[a] The *P*-value in the overall *F*-test of differences between interventions was 0.03 ($F = 3.48$). Data is presented as LS-means.

Table 5
Tail biting outbreaks at pen level within group. Listed according to days after intervention.

	Tail biting outbreak, day after intervention					
Intervention	2–3	4–5	6–7	8–10	> 10	Total
Straw		1			1	2
Haylage	1					1
Rope		2				2
Control	6	2	1	1	3	13

4. Discussion

To our knowledge, this is the first study to investigate the effect of allocating extra enrichment material after the first tail damage is observed to try to prevent a tail biting outbreak. Providing the enrichment material as an early intervention, just when the biting has started, ensures high novelty of the material, which increases attractiveness (Studnitz et al., 2007). Using manipulable materials as an early intervention measure instead of as a permanent preventive measure might increase the materials effect on tail biting due to increased attractiveness. This may further imply that less material or other kinds of materials can prevent tail biting outbreaks when used as an early intervention measure but not when used as a permanent preventive measure. However, the results should be interpreted with some caution because it was a minor study.

In previous studies, permanent access to various amount of straw has demonstrated to reduce the risk of a tail biting outbreak (20 g/weaner pig on the floor and 5 g/weaner pig in a straw rack Zonderland et al., 2008, 150 g/finisher pig Larsen et al., 2017 and deep straw (5 cm) Van de Weerd et al., 2006). In a review by D'Eath et al. (2014), different amounts of straw were ranked according to its relative preventive effect. Based on comparison of relatively few studies, this ranking suggests that small or larger amounts of straw seemed to prevent tail biting to almost the same extent. However, this ranking may be influenced by different definitions of tail biting across studies. In the present study a small amount of chopped straw, allocated daily just when the biting started, reduced the prevalence of tail biting outbreaks. A reason for this positive effect could be that the current environment and the possibility to explore influenced the development in tail biting behaviour to a greater extent, than earlier experiences with enrichment materials, as discussed by Van de Weerd et al. (2005) Additionally, and based on a minor study, Zonderland et al. (2008) reported that a small amount of straw provided twice daily stopped the biting in outbreak pens to the same extent as removing the biter.

Giving haylage in an elevated spherical cage probably increased the time the material was present in the pen compared to giving it on the floor. The material disappeared less rapidly through the slat openings, and probably this allocation method also increased the time pigs spent interacting with the material (pulling it out of the cage and exploring/chewing the material on the floor) (D'Eath et al., 2014). Earlier findings reported that straw in a rack reduced damaged tails to a greater extent than unchangeable materials (Van de Weerd et al., 2006; Zonderland et al., 2008), but straw in a rack was ranked lower across studies compared to straw on the floor (D'Eath et al., 2014). However, the accessibility of material (rack design) and the material presented in the rack probably influences the preventive effect on tail biting.

Sisal rope with a sweet-tasting lick block hanging in the middle of the pen did not reduce the risk of a tail biting outbreak compared to control pens. However, the result should be interpreted with caution as it was a minor study. In a review, ranking the attractiveness of enrichment materials, rope was ranked lower than straw (Studnitz et al., 2007). This could explain rope's non-significant effect on tail biting. Our casual observations suggested that the time pigs spent interacting with the material (not recorded) was spent on exploring the rope, rather than licking the sweet taste block, even though pigs do have a preference for sweet taste (Day et al., 1996). The preventive effect of the rope might have been improved if the rope itself had had a sweet taste, thereby combining sweet taste with a destructible material.

A common slurry system is the vacuum based system where the slurry is sucked out through pipes. In these systems, larger amount of litter material can block up the system as discussed by D'Eath et al. (2014). In the current study, intervention treatments were maintained until pigs were moved to the finisher facility. Causal observations indicate that, in pens with haylage, the slat openings near the solid floor were blocked, and the farmer had difficulties getting the material sucked through the slurry pipes. From a practical point of view it would, therefore, be relevant in future studies to investigate for how long the material should be present to put a stop to the tail biting behaviour. However, removing the material might redirect pigs' behaviour and trigger the tail biting behaviour to start again (Munsterhjelm et al., 2009).

Research indicates that upcoming tail biting outbreaks can be predicted based on changes in tail posture from curly to hanging (Zonderland et al., 2009; Lahrmann et al., 2018). Our results support these findings. We found that an increase in hanging tails was correlated with increasing number of damaged tails. However, the correlation was only evident when 20% or more of the tails were hanging at pen level. No difference in number of tail damaged pigs was observed in pens with pigs with 10% and 0% hanging tails. This is in agreement with Lahrmann et al. (2018), reporting approximately 15% hanging tails in pens not close to a tail biting outbreak. Overall, this indicate that other elements aside from tail biting also affect tail posture as discussed by Larsen et al. (2016).

Of the 60 pens entering the study, 14 pens had to be excluded (23%). In these pens, on the day when the first pig was observed with a tail damage, at least four pigs had a tail wound (tail biting outbreak definition). No severe outbreaks developed between the three weekly recording days, but we did miss the beginning of the tail biting behaviour in some pens. To detect tail damages, as an indicator of tail biting behaviour, just when it has started, tails should be checked at least once a day.

In control pens with no intervention, the development in tail damage was recorded until a tail biting outbreak. In 42% of the control pens (8 pens), a tail biting outbreak occurred within two to five days after the first pig was observed with a tail damage. In contrast, a tail biting outbreak did not develop during the study period in 32% of the control pens (6 pens). In comparison, the transition from one tail damaged pig to a tail biting outbreak was between half a week and 12 weeks in a finisher study (Statham et al., 2009), while in a weaner study the transition from bite marks to a tail wound was in average 7.5 days (SD 5.4 days) with a large variation between pigs (Zonderland et al., 2008). The transition time from one tail damage to a tail biting outbreak probably depends on the definition of a tail biting outbreak. In the present study, the definition of a tail biting outbreak was four tail damaged pigs (14% of the pigs/pen) irrespective of the freshness of the wound. In Zonderland et al. (2008), at least two pigs (20% of the pigs/pen) should have tail damage with one being a fresh wound. In Statham et al. (2009), they distinguished between underlying outbreaks (signs of tail biting observed during formal inspection) and severe outbreaks (blood in pen and severe damage on at least two pigs, 6.7% of the pigs/pen). However, the variation in transition time from one tail damaged pig to a tail biting outbreak indicates that a solitary tail damage does not always develop into a tail biting outbreak. This is supported by a study, reporting that in 43% of the pens with tail damaged pigs, one pig was observed with a tail wound without further escalation of the tail biting behaviour into a tail biting outbreak (Zonderland et al., 2008).

Time spent getting every pig up and observe damaged tails from outside the pen was not monitored. However, it is estimated that it took one to two minutes per pen including writing down tail posture and tail injury as reported in Lahrmann et al. (2018). If tails were to be checked in this way during the daily health monitoring, it would, in addition to the time spent providing extra material, take roughly 30–60 s per pen.

5. Conclusion

An early intervention with provision of a small amount of straw on the floor or haylage in a spherical metal mesh cage reduced the risk of tail biting outbreak compared to control pens with no intervention. In comparison, the use of rope with a sweet block as an early intervention did not reduce tail biting outbreaks significantly compared to pens with no intervention. The results should, however, be interpreted with some caution due to the relatively small sample size.

In control pens with no intervention, a tail biting outbreak developed in 42% of the pens within two to five days after the first tail damage was observed. In 32% of the control pens a tail biting outbreak never occurred. This indicates that tail biting behaviour did not, in every case, escalate from one tail damaged pig into a tail biting outbreak.

Even though this was a small study, the results suggest that tail biting outbreaks can in many cases be prevented by giving the pigs access to extra enrichment material, when the first minor tail damage is noticed. Therefore, a thorough regular inspection of tails and the use of early interventions could be one way to reduce the prevalence of tail biting outbreaks and by it the need for tail docking.

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9.4 Paper IV

Lahrmann, H.P.[1,*], Hansen, C.F.[1], D'Eath, R.B.[2], Nielsen, J.P.[3], Forkman, B.[4] Comparing straw, rope and Bite-Rite as treatments for tail biting outbreaks in weaner pigs. In prep manuscript.

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Comparing straw, rope and Bite-Rite as treatments for tail biting outbreaks in weaner pigs.

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Short title: A small amount of straw most efficiently stopped tail damage

Keywords: pigs, tail biting, tail biting outbreak, enrichment material, straw

Abstract

Tail biting is an injurious behaviour that can rapidly spread in a group of pigs. Most importantly tail biting outbreaks should be prevented. However, if a tail biting outbreak occurs, is it crucial that the biting behaviour can be stopped. In the present study, we examined the effect of three different curative treatments implementable in commercial piggeries in pens with a tail biting outbreak. The investigated curative treatments were; straw on the floor (7 g/pig/day), hanging rope and a commercially available hanging plastic enrichment with four chewable rods (Bite-Rite). The study included 1 987 undocked nursery pigs from 6-30 kg distributed in 65 pens (30 pigs/pen). A tail biting outbreak was defined as four pigs in a pen with a tail wound – either fresh or scabbed. To determine the day of the tail biting outbreak pigs were individually tail scored three times weekly prior to the outbreak. After a tail biting outbreak, pigs' tails in that pen were scored once weekly. The effects of the curative treatments were assessed based on whether the tail damage escalated further. The biting behaviour escalated if four pigs had a fresh tail wound or a biter had to be removed from the pen. Results demonstrated that straw the straw treatment prevented an escalation in tail damaged pigs in approximately 75 % of the pens, whereas rope prevented an escalation in 65 % and Bite-Rite in 35 % of the pens. Straw was significantly better than Bite-Rite (P<0.05), while rope did not differ significantly from the other two treatments. In pens without a subsequent escalation in tail biting, fewer pigs had tail damage on day 14 after the curative treatment was provided than on day 0 and day 7 (P<0.001). This suggests that it took more than seven days for a tail wound to heal with the allocated enrichment materials. Recordings of tail posture and tail damaged pigs demonstrated increased number of hanging tails with increased number of tail damaged pigs two days later (P<0.01). In conclusion, the straw treatment was the most effective of the three interventions tried. However, more research is needed

to investigate if other enrichment materials or allocation strategies implementable in commercial piggeries can prevent an escalation in tail damage more effectively during a tail biting outbreak.

1. Introduction

Tail biting in pigs is an abnormal painful behaviour and has been reported both in conventional and in free-range/ organic production (Alban et al., 2015; Kongsted and Sørensen, 2017). To prevent tail biting it is essential to reduce the risk factors triggering the behaviour (Taylor et al., 2010), and a wide range of risk factors has been suggested in epidemiological studies such as; enrichment, stocking density, floor type, air quality and health (Hunter et al., 2001; Scollo et al., 2016).

To minimize the risk of tail damage due to tail biting most pigs within the EU are tail docked, but tail docking is undesirable as it does not remove the stressors triggering the abnormal behaviour (EFSA, 2007). Even with a constant focus on minimizing risk factors tail the levels of tail damaged pigs will increase if pigs are not tail docked (D'Eath et al., 2016; Lahrmann et al., 2017; Larsen et al., 2017) due to its multifactorial origin (Schrøder-Petersen and Simonsen, 2001). Thus, if a termination of tail docking is not going to lead to worse welfare (due to increased tail damaged pigs), it will mean reducing background risk factors, and require effective interventions.

Tail biting by single pigs may, if not identified in the early stages, develop into a tail biting outbreak (Edwards, 2011). In a pen with a tail biting outbreak the tail biting has intensified leading to several tail damaged pigs (EFSA, 2007) and the tail biting will continue if an intervention is not conducted.

Giving pigs access to different kinds of enrichment have earlier been reported to reduce tail damage (Zonderland et al., 2008; Ursinus et al., 2014; Larsen et al., 2017).

The most frequent studied preventive enrichment material is straw on the floor in various amounts (reviewed by D'Eath et al. (2014); Brunberg et al. (2016)). D'Eath et al. (2014) discussed in order to avoid a large waste, as well as problems with the slurry system, litter material such as straw is only practicable in pens with a solid floor and in small amounts. Other solutions are therefore needed for production systems without a solid floor to stop the tail biting during an outbreak. Hanging materials could be a solution in these systems. However, the effect of hanging materials on tail damage during an outbreak has not been investigated in previous studies (reviewed by D'Eath et al. (2014)).

Only one experimental study has investigated the curative effect of interventions in pens with a tail biting outbreak (reviewed by Valros et al. (2016)). This weaner study with undocked pigs, reported no difference in tail wound freshness in pens with a tail biting outbreak between removing the biting pig or giving extra straw (20 g/pig/day) on the floor (Zonderland et al., 2008). Systematic studies evaluating the effect of different curative treatments are therefore needed (Edwards, 2011; D'Eath et al., 2014). Curative treatments in this context refer to interventions aiming at decreasing the level of tail biting by measuring tail damaged pigs in pens with a tail biting outbreak.

Removing the biting pig as an intervention during an outbreak has also been reported in three farmer surveys. In a Dutch survey, farmers with tail docked pigs most frequently reported “removing biters” and “removing bitten pigs” as an intervention when tail damage occurred (Bracke et al., 2013). These results are in line with a Finnish and Swedish survey. In these surveys, the three most frequent interventions in pens with tail damaged pigs were; identifying the biter/remove biters, providing extra litter material (straw or wood-shavings) and remove bitten pigs (Valros et al., 2016; Wallgren et al., 2016).

Knowledge of the effect of different intervention strategies as curative measures on tail damage development during a tail biting outbreak is crucial to reduce the negative welfare impact of the outbreak. However, very little research has been conducted on the effect of different enrichment devices as a curative measure in pens with a tail biting outbreak. The aim of the present study was therefore to examine the effect of either a small amount of straw on the floor, hanging rope or Bite-Rite on tail damage in pens with a tail biting outbreak. These enrichment types were chosen due to their possible practical implementation if the material successfully ceased tail damage. As previous studies reported less use of enrichment in pens with Bite-Rite compared to straw (Van de Weerd et al., 2006) and because rope is more destructible, it was hypothesised that straw on the floor and rope would reduce tail damage more efficiently than Bite-Rite.

2. Material and methods

This experiment was a continuation of the work presented in Lahrmann et al. (2018b) using the same study subjects. However, while (Lahrmann et al., 2018b) dealt with identifying behavioural changes before tail biting outbreaks, the current study focuses on the effect of interventions in pens with tail biting outbreaks. The study was carried out at a commercial piggery from November 2015 to February 2016.

2.1 Ethical consideration

This experiment was conducted in accordance with the guidelines of the Danish Ministry of Justice, Act No. 382 (June 10, 1987) and Acts 333 (May 19, 1990), 726 (September 9, 1993) and 1,016 (December 12, 2001) with respect to animal experimentation and care of animals under study.

2.2 Experimental design

The study was designed to compare the effect of three different curative treatments on tail damage in pens with a tail biting outbreak. On the day of the tail biting outbreak (see Section 2.4 below for outbreak definition), one of three treatments was randomly allocated to the pen: straw on the floor, hanging rope or a Bite-Rite. To follow the development in tail injuries tails were recorded once weekly after an outbreak was noted.

2.3 Animals and housing

This study included 1 987 undocked DanBred crossbred ((Landrace x Large White) x Duroc) nursery pigs from 6 to 30 kg. Pigs originated from four different farrowing batches with 458 to 525 pigs per batch. Pigs were born in a farrowing system with loose sows (for pen design details, see Pedersen et al. (2015)). Iron injections (Uniferon, Pharmacosmos, Holbæk, Denmark), grinding of the needle teeth (Tandsliber proff, Hatting, Horsens, Denmark) and surgical castration of male piglets with a scalpel were carried out on day three or four after birth. Male piglets were given analgesic just before castration (Melovem® 5 mg/ml). Throughout the lactation period, piglets had access to the straw the sow pulled from the straw rack. Approximately two weeks after farrowing, piglets were offered solid feed on the floor in creep area. Two days before weaning, pigs were ear tagged, individually weighed and their sex were noted. The lactation period was 27.8 days (SD 2.9) and pigs weighed 5.8 kg (SD 1.5) at weaning. After weaning pigs were transported to the nursery facility close to the sow facility (1.5 km).

At the nursery facility, pigs were sorted by size within a batch and randomly allocated to nursery pens with 30 pigs/pen (SD 2; 0.35 m^2/pig). Gender distribution was in average 49.2 % (Range; 32.2 % to 77.4 %) gilts per pen. The four experimental rooms consisted of 26 or 30 pens and between 18 to 20 pens per room were included in the experiment. Pens measured 4.85×2.18 m (length × width) with 7.1 m^2 solid floor and 3.5 m^2 cast iron slatted floor. A 2.16 m^2 adjustable covering was placed above the solid floor in the lying area. Two adjacent pens shared a dry feed dispenser with two nipple drinkers, one placed on each side of the feed dispenser (MaxiMat Weaner 7 to 60 kg, Skiold A/S, Sæby, Denmark). Additionally, a separate water supply (drinking bowl) was placed next to the feed dispenser towards the slatted floor. Each pen was equipped with two wooden blocks hanging in a chain just above the floor without touching the floor to ensure permanent access to enrichment according to legislation (Anonymous, 2017). Pens were provided daily with approximately 350 g of finely chopped straw (Easy Strø, Easy Agri Care, Nykøbing Mors, Denmark, http://easy-stroe.dk/files/easy-str%c3%b8_UK.pdf) on the solid floor. Artificial lighting was on from 06:00 am to 22:00 pm.

The rooms were ventilated by a negative pressure air flow through wall air inlets on one side of the building (SKOV A/S, Glyngøre, Denmark). The room temperature at weaning was 24 °C and it was gradually lowered to 19 °C on day 42. Thermostatically controlled floor heating pipes were placed inside the floor in the lying area giving a floor temperature of 30 °C at the start of the study. The floor heating was turned off on day 14.

Pigs were fed three different home-mixed compound diets (*ad libitum* access) from 6-30 kg. The diets were formulated to fulfil the nutritional requirements of pigs of this age and genotype. Phase one diet allocated from approx. 6 to 10 kg (17.4 % crude protein) consisted of 64.0 % wheat, 22.0 % premix of minerals and vitamins (HeavyPig 3 20 %, Vilomix, Mørke, Denmark), 10.5 % fish meal and 3.5 % soy oil. Phase two diet allocated from approx. 10 to 15 kg (18.1 % crude protein) consisted of 44.4 % wheat, 25.0 % barley, 15.0 % toasted soy bean, 8.2 % premix of mineral and vitamins (MIN 27600, Vilomix, Mørke, Denmark), 5.0 % fish meal and 2.4 % soy oil. Phase three diet allocated from approx. 15 to 30 kg (18.4 % crude protein) consisted of 48.8 % wheat, 25.5 % toasted soy bean, 20.0 %

barley, 4.2 % premix of mineral and vitamins (MIN 27603, Vilomix, Mørke, Denmark) and 1.5 % soy oil.

The transition between feed compounds depended on the average body weight in the pen at weaning and was gradually conducted over a seven or 14-day period. Pigs were housed at the nursery location for six and a half weeks before being moved to the finisher facility.

During the stock person's daily inspection, pigs with clinical signs of disease were treated with antibiotics when needed according to the herd veterinarian's recommendations. Unthrifty animals and pigs with severe tail lesions (more than half the tail missing or swelling as a sign of infection) were moved to hospital pens. Pigs were individually weighed two days before being moved to the finisher facility. Biters and pigs moved to hospital pens were not weighed.

2.4 Tail biting outbreak (day 0)

A "tail biting outbreak" was defined in this study as occurring when at least four pigs in a pen (approx. 13 % of the pigs) had a tail wound – either scabbed or fresh, which was more severe than minor superficial scratches (Table 1). The day of the tail biting outbreak was set as day 0.

2.5 Tail scoring and tail posture

Tail damage severity and tail posture were recorded in the same way as by Lahrmann et al. (2018b). From weaning until a tail biting outbreak, tails of each pig were scored three times weekly (Monday, Wednesday and Friday) using the system shown in Table 1 to determine the day of the outbreak (presented in Lahrmann et al. (2018b)). During tail scoring, tail damage severity, wound freshness, tail length and tail swelling on injured tails were recorded according to the criteria listed in Table 1. The stock person did not observe any tail biting outbreaks between recording days.

Table 1. Tail injury classification after Lahrmann et al. (2018)

Tail scoring	Description
Damage severity	
No	No visible tail lesion. The earlier lesion is healed
Minor scratches	Minor superficial scratches
Wound	Visible wound and tissue damage
Wound – tail end will fall of	The outer part of the tail has almost been bitten off. During healing, the tail tip will fall off
Damage freshness	
Intact scab	The wound is covered with a hard, dry scab
Not intact scab	The wound is covered with a scab, but cracks in the scab and dried blood/ fresh tissue are visible
Fresh wound – not bleeding (weeping)	Skin is broken, no scab, no blood – only weeping.
Fresh wound - bleeding	Fresh lesion and fresh blood are present
Tail length	
Intact	Full-length tail
Outer part is missing	The outer part of the tail is missing
More than half is missing	More than half of the tail is missing
< 1 cm left of the tail	Less than 1 cm of the tail is left
Swelling	
No	No swelling
Yes	Swollen red tail indicating an infection

In pens with a tail biting outbreak, tails were scored once weekly on day 7, day 14, day 21 and so on after the outbreak. The tail scoring continued until an escalation in tail damaged pigs was observed (see definition in the curative treatment paragraph below).

The tail posture was recorded three times weekly at pen level from weaning until the pen left the experiment according to the criteria mentioned above. The tail posture on standing pigs was recorded from outside the pen between 0700- 1500h just before the tails were scored. Tail posture was scored as either up (curly) or hanging/tucked (loosely hanging straight tail below the horizontal line or a straight tail pressed into the body). The observer counted the number of standing pigs and immediately after recorded tail posture. Even though not recorded, it took on average one or two minutes per pen to record tail posture, and with the used tail posture definition, the tail posture could be recorded for all pigs.

2.6 Treatments

One of three curative treatments was in a predetermined random order allocated to the pen on the day of the tail biting outbreak (day 0): Straw, rope or a commercially available hanging plastic enrichment with four chewable rods (Bite-Rite, Ikadan Systems A/S, Ikast, Denmark, http://www.ikadan.dk/Default.aspx?ID=3195). A curative treatment was provided in 65 pens and it was maintained until the pigs were moved to the finisher facility (study end).

In pens with straw (23 pens) approximately 200 g (7 g/pig/day) of chopped wheat straw (chopped during harvest in a combine harvester) were provided on the solid floor once daily. This was in addition to the 350 g of finely and thermal treated chopped straw (Easy Strø, Easy Agri Care, Nykøbing Mors, Denmark, http://easy-stroe.dk/files/easy-str%c3%b8_UK.pdf) which all pens received daily throughout the study period.

In pens with rope (22 pens) a coil of sisal rope (20 mm in diameter) was placed above the pen. The rope was pulled from the coil leaving roughly 30 cm of rope on the solid floor, and the top end at the coil secured so that no more rope could be pulled out by the pigs. The rope was provided in the middle of the pen, approximately one meter from the slatted floor. A knot was tied about 20 cm from the rope end to reduce consumption. If the rope end was consumed the knot was loosened and new rope was provided the following day in the same way as described above.

In pens with a Bite-Rite, the device was suspended over the middle of the pen at the same location as the rope (20 pens). The plastic rods were located at a height at which pigs could easily reach them and chew on them - both standing and sitting. As pigs grew, the Bite-Rite was gradually lifted.

The effect of the curative treatments on tail biting behaviour were established based on whether there was an escalation in tail damaged pigs or not. When the term 'an escalation in tail damage' is applied in this paper, it refers to the sum of pens in which a tail biter was removed and pens observed with four fresh wounds or more. The four fresh tail wounds could either be observed during weekly tail inspection days (see Section 2.5) or during daily health inspection between recording days.

2.7 Removing biters and victims

Biters were pigs observed continuously biting the tails of pen mates. If a pig was observed walking from one pig to another chewing/biting the tail so hard, that the receiver screamed, reacted by suddenly moving away or turning against the biting pig, it was removed from the pen. Biters were identified during the daily health inspections by stockperson or at the weekly tail scorings. When biters were observed, they were removed from the pen. Tail biting victims with severe tail lesions defined as more than half the tail missing or swelling as a sign of infection were moved to a hospital pen.

2.8 Statistical analysis

Statistical analyses were performed in SAS Enterprise Guide 7.1 (SAS Institute Inc., Cary, NC, USA) with a significance level of $P<0.05$. An intervention was conducted in 65 pens, but in four pens the tail biting outbreak occurred within the last week of the experiment. These four pens were excluded from the analyses because the effect of the curative treatment could be tested for less than one week. Tail injuries were grouped according to severity and tail length, but irrespective of damage freshness (0=no tail damage, 1=tail damage present and full tail length (mild), 2= tail damage present and tail loss or swollen tail (moderate)) before statistical analysis.

The difference in tail damaged pigs between treatments on day 0 and the effect of number of tail damaged pigs on day 0 on the risk of an escalation in tail damage was analysed using the GLIMMIX procedure to fit a Generalised Linear Mixed Model. Treatment and days after weaning until outbreak were fitted as systematic effects and pen was a random effect in the model.

The GLIMMIX procedure was also used to analyse the effect of treatment (straw, rope or Bite-Rite) at pen level on a potential escalation in tail damage (removing biter or at least four fresh wounds). Furthermore, the effect of treatment on tail damage severity at pig level was also analysed using the GLIMMIX procedure. Days from weaning until treatment was included as a fixed effect and batch as random effect in both models.

The duration of tail wound healing was analysed in pens without a subsequent escalation in tail damage and that had been at the experimental facility for at least 14 days after the intervention. The pen was the experimental unit in this analysis. Data were analysed using the MIXED procedure with day after intervention (day 0, 7 or 14) as systematic effect and pen as a random effect.

Results concerning victims' weight gain were analysed at pig level. Data regarding weight gain was analysed using the MIXED procedure with tail damage severity and weaning weight as fixed effects, and pen as a random effect. Sex had no effect on weight gain and was excluded from the model.

Results from data analysis in the GLIMMIX and the MIXED procedure are presented as Least Square means (LSmeans) and standard error (SE).

The impact of sex, on the probability of becoming a tail biting victim and tail damage severity were analysed using a χ^2-test. Sex were recorded for 1947 pigs of the 1987 pigs included in the study.

Hanging tails were recorded three times weekly (Monday, Wednesday and Friday). Thus, depending on the weekday of the tail biting outbreak, the previous recording of hanging tails was either two or three days earlier. In the analysis of the correlation between hanging tails and number of tail damaged pigs observed on the following recording day (day 7 or day 14), hanging tails recorded on the previous recording, - day 4 or 5 and day 11 or 12- were summed and reported as day 5 and day 12, respectively. The correlation between hanging tails and number of tail damaged pigs on day 0, 7 and 14 were analysed using PROC CORR at pen level.

3. Results

Of the 65 pens included in the study, a tail biting outbreak occurred in four pens within the last week before pigs were moved to the finisher facility (one straw, two ropes and one Bite-Rite). These pens were excluded because the effect of the treatment could be followed for less than a week leaving 61 pens which were included in the analysis.

On average, a tail biting outbreak developed 25 days (*SD* 10.2; *Range* 9-45 days; *Median*; 23 days) after weaning (Figure 1), and 6.7 pigs/pen (*SD* 3.4; *Range* 3-21 pigs) had tail damage at that timepoint (day 0). On day 0, when one of the three curative treatments were provided the number of tail damaged pigs at pen level did not differ between treatments ($F_{2,55}$ = 0.19, P = 0.83), and the number of tail damaged pigs on day 0 did not affect the risk of a subsequent escalation in tail damage ($F_{1,55}$ = 0.10, P = 0.76).

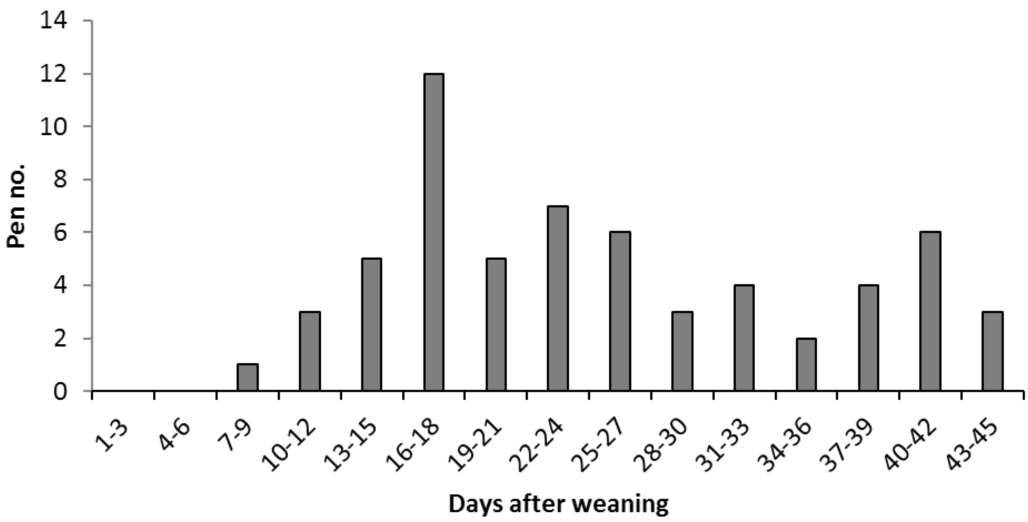

Figure 1. Incidence of first tail biting outbreak at pen level during the study period (n = 61).

In total 843 pigs (42 %) of the 1 987 pigs were recorded with tail damage including scratches. Of the tail damaged pigs, 35 % had a shortened tail (15 % of the 1 987 pigs). The remaining pigs with tail damage had a full-length tail.

3.1 Effect of curative treatment

Escalation in tail biting (four fresh tail wounds or removing a biter) occurred on average 14 days after day 0 with a large variation between pens (*SD* 9.2; *Range* 2-34 days). In four pens, removing the biting pig was the reason why the pen was removed from the study, whereas in 21 pens in the presence of four freshly tail damaged pigs was the reason. The tail damage escalated (sum of removed biting pig and pens with four fresh wounds) in significantly more pens with Bite-Rite than in pens with straw (Figure 2). However, there were no significant differences between rope and either Bite-Rite or straw.

In total, fewer pigs received tail damage in pens provided with straw (16.7 %) compared to Bite-Rite (25.6 %; $t_{(1811)} = 3.81$, $P < 0.001$) and rope (22.8 %; $t_{(1811)} = 2.69$, $P < 0.01$). Whereas no difference in tail damaged pigs was observed between rope and Bite-Rite pens ($t_{(1811)} = 1.12$, $P = 0.26$).

3.2 Tail wound healing

Combining data for the three curative treatments, in pens with no subsequent escalation in tail damage (n = 27) 20.7 % of the pigs per pen (6.4 pigs per pen; *SD* 3.5) had tail damage on day 0. In these pens, fewer pigs had tail damage on day 14 than on day 0 and day 7, but there was no difference between day 0 and day 7 (*P* = 0.15, Figure 3)

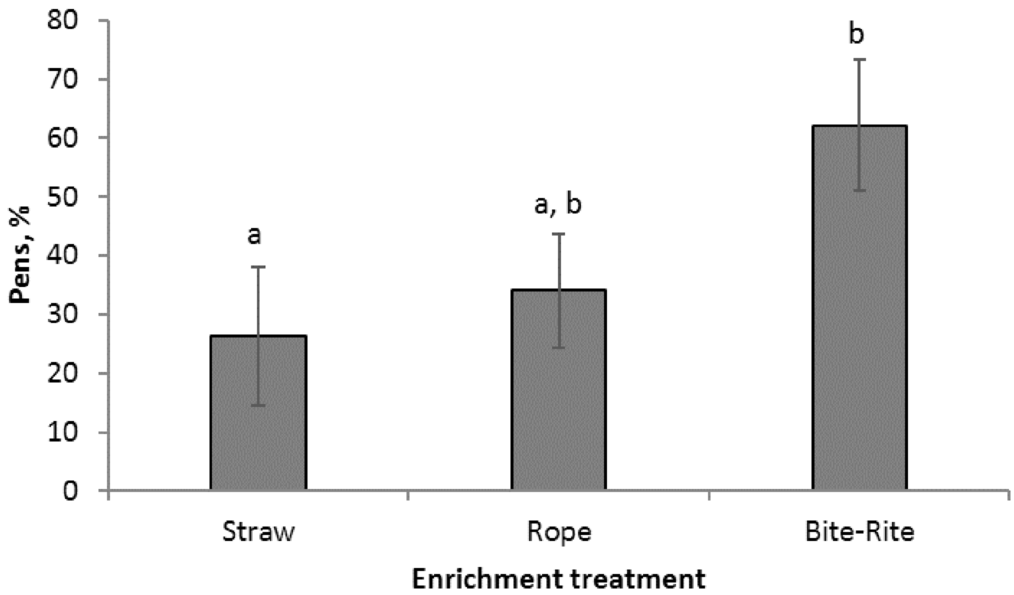

Figure 2. Percentage of pens with an escalation in tail damage presented as LSmeans (± SE) according to treatment. Different superscript (a, b) indicates significant difference of *P* < 0.05 between treatments.

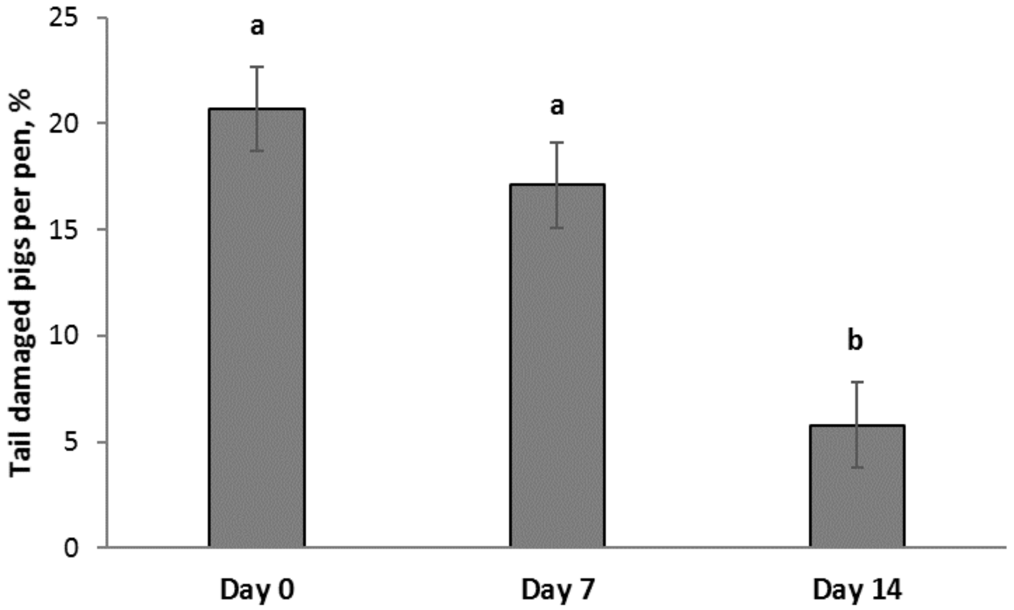

Figure 3. Percentage of tail damaged pigs per pen on day 0, day 7 and day 14 (LSmeans ± SE) after the intervention in pens without an escalation in tail damage (n = 27). Different superscripts (a, b) indicate significant difference of $P < 0.001$.

3.3 Victims and biters

Pigs with mild or moderate tail damage had higher weight gain during the study period (23.5 kg and 24.2 kg respectively) than pigs without a tail damage (22.8 kg, $P < 0.01$, *SE* 0.33). Additionally, among pigs observed with a tail injury during the study period, pigs with a moderate tail damage had a higher weight gain than pigs with a mild tail damage ($P < 0.05$, *SE* 0.34). Sex did not influence the probability of becoming a tail biting victim ($\chi^2_{(1,\ N = 1947)} = 1.10$, $P = 0.29$) or influenced the severity of the tail injury ($\chi^2_{(2,\ N = 826)} = 0.10$, $P = 0.95$).

In total 22 biters (15 barrows and 7 gilts) were identified and removed from 15 different pens (straw; 4 pens, rope; 3 pens, Bite-rite; 8 pens) during the experiment (61 pens). Three biters were removed from two pens (rope; 1 pen, Bite-rite; 1 pen), two biters from three pens (straw; 2 pens, Bite-rite; 1 pen) and one biter from ten pens (straw; 2 pens, rope; 2 pens and Bite-rite; 6 pens). On average, a biter was identified and removed 15.4 days (SD 10.1) after the intervention.

3.4 Correlation between tail posture and tail damages

The number of hanging tails was positively correlated with the number of pigs with tail damage recorded on the same day on day 0 and day 7 (Table 2). Additionally, a correlation was also present between number of hanging tails recorded on day 5 and tail damaged pigs on day 7 ($r = 0.53$, $P < 0.01$), and hanging tails on day 12 and tail damaged pigs on day 14 ($r = 0.58$, $P < 0.01$).

Table 2. Correlation between hanging tails and tail damaged pigs at pen level (n). The correlation was compared between hanging tails and tail damaged pigs recorded on the same day or compared between hanging tails recorded two days prior to the day where tail damaged pigs were recorded.

Recording day Hanging tails	n	Tail damaged pigs	n	Pearson Correlation Coefficient	*P*-value
Day 0	65	Day 0	65	0.42	< 0.001
Day 7	47	Day 7	47	0.53	< 0.001
Day 14	25	Day 14	25	0.36	0.08
Day 5	31	Day 7	30	0.53	< 0.01
Day 12	19	Day 14	19	0.58	< 0.01

4. Discussion

Providing straw on the floor during an ongoing tail biting outbreak reduced the risk of a further escalation in tail damage more efficiently than providing a Bite-Rite. Numerically, rope fell between the other two treatments, but no significant difference was demonstrated between pens provided with rope and pens provided with straw or Bite-Rite.

While a previous study (Lahrmann et al., in press) has shown that enrichment may prevent tail damage from escalation, once it has just started, this is, to our knowledge, the first study to compare the effect of straw, rope and Bite-Rite as curative measures during an ongoing tail biting outbreak. An escalation in tail damage was observed in 26 % of the straw pens, 34 % of the rope pens and 62 % of the Bite-Rite pens. Thus, even if the most efficient curative treatment was applied, the tail damage escalated in approximately one in four pens. This could indicate that a different intervention strategy or other kinds of interventions are needed to stop the biting behaviour completely during a tail biting outbreak. These interventions could include removing tail damaged pigs, providing the materials used her in combination, providing the materials used here in greater quantity, providing other types of enrichment or perhaps shifting between enrichment materials during the post-outbreak phase. In a study by Zonderland et al. (2008), allocation of straw twice daily (20 g/pig/day) or removing the biting pig as curative treatments were equally likely to stop tail biting. The treatment effect was measured as the prevalence of pigs with a fresh wound in following ten days after the tail biting outbreak. However, ten days after the intervention, 11 % of the pigs still had a fresh tail wound, compared with 25 % on the day of the outbreak, suggesting that even these interventions did not stop the biting behaviour completely.

The curative treatments applied in the present study were chosen because they could be implemented in current production systems. It could be that providing a larger amount of straw and thereby ensuring access for a longer period of the day would have reduced the escalation in tail biting even more efficiently (Munsterhjelm et al., 2015). Since, previous studies have reported that increasing amounts of straw, increased the time pigs interacted with the material (Oxholm et al., 2014; Jensen et al., 2015). There are, however, practical problems with larger amounts of straw, as it increases the risk of the material accumulating in the slurry canals or blocking up the pipes, is systems where the slurry is sucked out of the stable through pipes (D'Eath et al., 2014). To ensure access to straw for a longer period during the day, Oxholm et al. (2014) reported that more frequent allocation of the same total amount of straw (four times daily vs once a day) ensured more straw left in the pen the following day. Another approach could be to give the straw in a rack, which would probably also increase accessibility. However, straw in a rack might not be as effective as straw on the floor if pigs cannot pull the straw from the rack and on to the floor (Zonderland et al., 2008). On the contrary if pigs can easily pull straw from the rack, this allocation method might double the occupation value for the pigs. First pigs must pull the straw from the rack, and then they can root and chew at that straw on the floor.

Another possibility could be to allocate a material that pigs find more attractive than straw. In a review by Bracke et al. (2006) compound enrichment (mixtures) was ranked higher than straw. These materials might stop tail biting more efficiently, because pigs find them more attractive even in smaller amounts. However, studies of tail biting like the current one are required to establish the materials influence during a tail biting outbreak, rather than just their attractiveness to pigs. Furthermore, it is relevant to establish which enrichment features are most important beside destructibility, manipulability and edibility (Studnitz et al., 2007) in pens with tail biting – novelty, permanent access or both.

In pens provided with rope a knot was tied approximately 20 cm from the rope end. The rope treatment might have prevented an escalation in tail damage to a greater extent without the knot, because when the rope beneath the knot was consumed, the rope was no longer destructible and chewable. This may have caused less interaction with the material (Studnitz et al., 2007) until new rope was released the following day and it could perhaps explain the continuous tail biting. It may also be that several pieces of rope are needed to completely stop the biting. This would give more pigs access to the material simultaneously and may avoid pigs experiencing frustration due to lack of access to the material as discussed by Docking et al. (2008). However, access to four toys versus one toy made of alkathane piping did not increase the proportion of observations at which pigs interacted with the material in a minor study by Scott et al. (2007) (eight pens per treatment).

Novelty, besides destructibility and manipulability, is an important feature to keep pigs interested (Studnitz et al., 2007). Therefore, a shift between different types of hanging materials could have been more effective. Perre et al. (2011) reported in a minor study (6 pens per treatment) that shifting between hanging enrichment objects reduced tail damage and biting behaviour compared to only providing a chain.

In the present study two criteria were used to determine if the curative treatment stopped the tail biting behaviour; an escalation in fresh wounds (direct measure) and removing a biter (indirect measure). Removing the biting pig was used as a criterion as this indirect measure also reflects whether the curative treatment served the primary purpose; to stop the tail biting behaviour. In four pens, the biting pig was removed before an escalation in tail damaged pigs was observed. In the remaining pens with biters, biters were removed after an escalation in tail damaged pigs were observed. The biting pig was perhaps already present on the tail biting outbreak day, but was not detected, because the biting pigs cannot always be identified (Schrøder-Petersen and Simonsen, 2001; Zonderland et al., 2008).

In pens without a further escalation in tail damage, fewer pigs had tail damage on day 14 than on day 0 and day 7. This suggests that it took more than seven days for a tail damage to heal completely with the allocated enrichment materials. These results are supported by Lahrmann et al. (2017) reporting that 89 % of the tail wounds healed within 14 days. However, as discussed by Lahrmann et al. (2017) the duration of the wound healing is clearly affected by the severity of the wound.

Castrated males have, in some studies, been more likely to become tail biting victims when recorded on the farm (Van de Weerd et al., 2005; Lahrmann et al., 2017) or at the abattoir (Valros et al., 2004; Keeling et al., 2012). However, as in this study, others recording tail damage on-farm reported no difference due to sex (Zonderland et al., 2010; Di Martino et al., 2015).

On average, the tail biting outbreak occurred 23 days after weaning (Range 5-45 days), which is in line with Zonderland et al. (2008) reporting tail biting outbreaks in 50 % of the pens (median) 24 days after weaning (Range 8-31 days). In agreement Veit et al. (2016) reported that tail damage began to occur two to three weeks after weaning.

The earlier finding that an increase in hanging tails is correlated with an increase in tail damaged pigs recorded on the same day (Zonderland et al., 2009; Lahrmann et al., 2018a) was confirmed in the current experiment. In addition, Lahrmann et al. (2018b) reported more hanging tails in pens with at least six tail damaged pigs on the following day than in pens with 4-5 tail damaged pigs. Furthermore, results from this study showed that there was a correlation between direct observation of hanging tails at pen level and the number of tail damaged pigs two days later. Altogether these repeated findings suggest that tail position is affected for several days and therefore is a reliable way to evaluate the severity of a tail biting outbreak.

5. Conclusion

Providing straw on the floor during a tail biting outbreak reduced the risk of an escalation in tail damage more effectively than providing a Bite-Rite, while rope reduced tail damage at an intermediate level which was not significantly different from either straw or Bite-Rite.

The curative treatments applied in the study were chosen because they could be practical to use under commercial conditions. However, tail damage escalated in approximately one in four straw pens. This indicates that other enrichment treatments or different interventions strategies might be needed to stop the tail biting behaviour completely. However, future studies comparing the effect of different interventions strategies during a tail biting outbreak are needed to establish this.

In pens without a subsequent escalation in tail biting, fewer pigs had tail damage on day 14 after the curative treatment was provided than on day 0 and day 7. This suggests that it took more than seven days for a tail wound to heal with the allocated enrichment materials.

Results further showed that increasing hanging tails were correlated with an increase in the number of tail damaged pigs. This relation between hanging tails and tail damaged pigs have also been reported in earlier studies. These repeated findings, indicate that tail position is affected for several days and therefore is a reliable method to evaluate the extent of tail damaged pigs.

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10. Appendix

10.1 Tail damage classification – picture sheet

Tail damage - severity	Wound - Freshness	Tail length	Swelling
0 No tail damage	0 No wound	0 Full length tail	0 No swelling
			
1 Red	1 Intact scab	1 Shortened tail	1 Swelling
	 	  	
2 Bite marks/scrathes	2 Not intact scab – older blood, red tissue	2 > half the tail is missing	
 			
3 Wound	3 Fresh wound – not bleeding (weeping)	3 < 1 cm left of the tail	
			
4 Wound - tail end will fall of	4 Fresh wound - bleeding		
			

10.2 Pilot study graphs

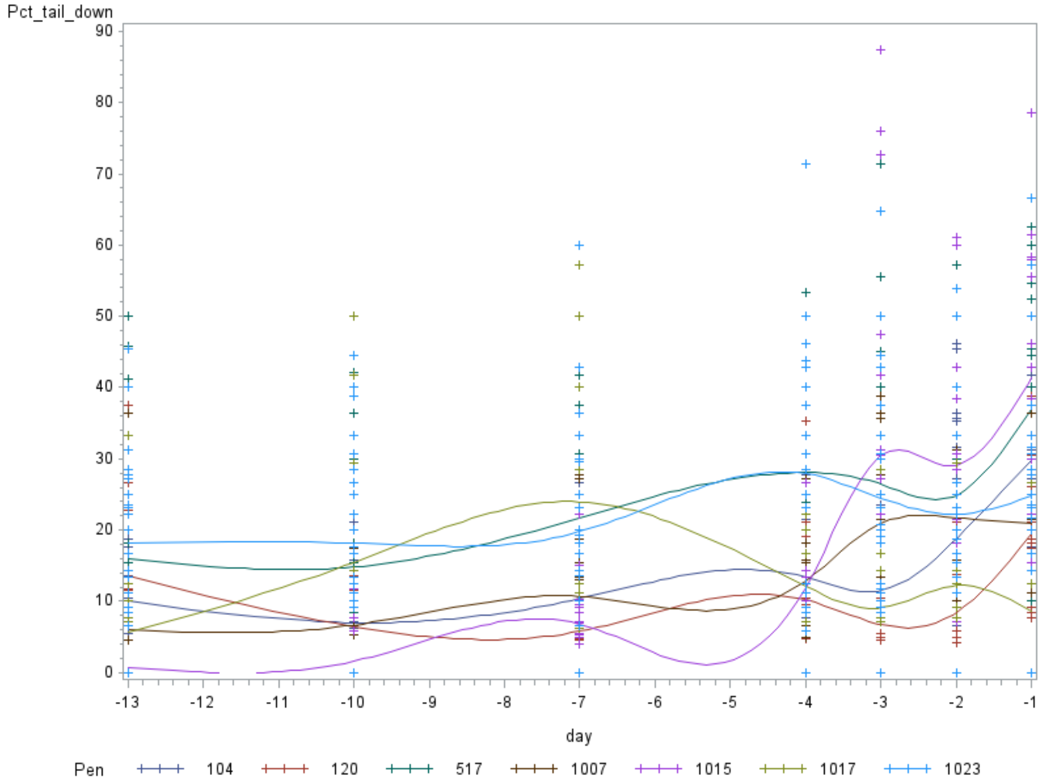

Figure A1 Percentage of tails down on day -13, -10, -7, -4, -3, -2 and -1 before an outbreak (7 pens).

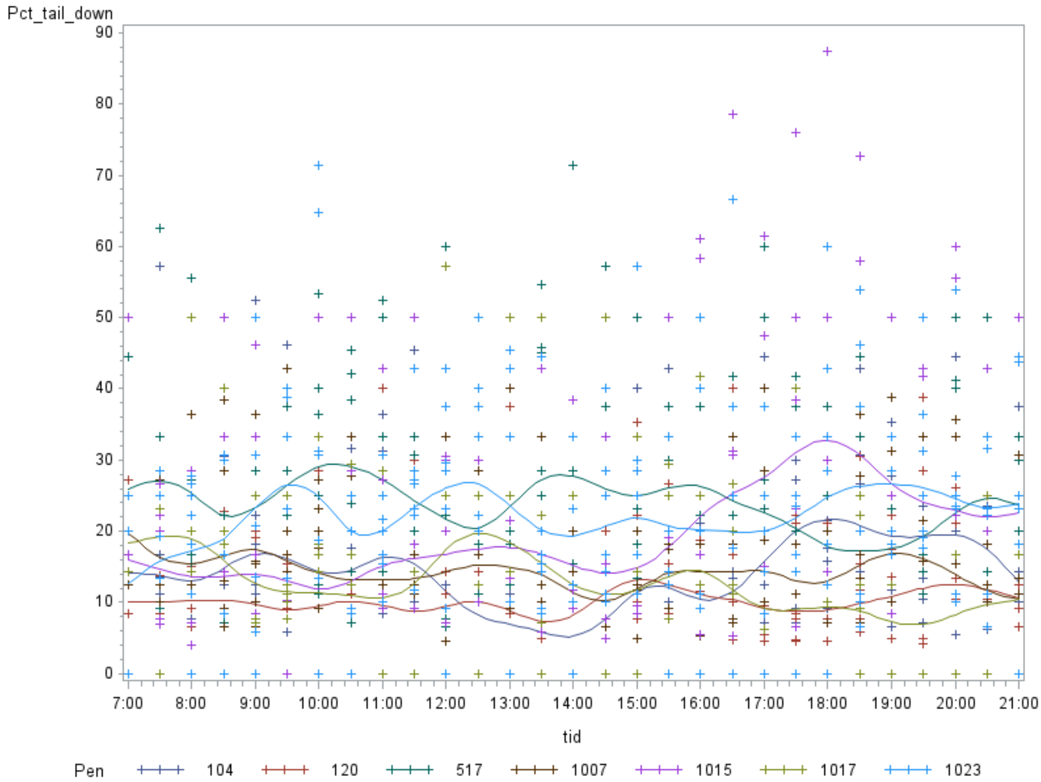

Figure A2 Percentage of hanging tails from 0700-2100 h on the pilot study recording days (7 pens).

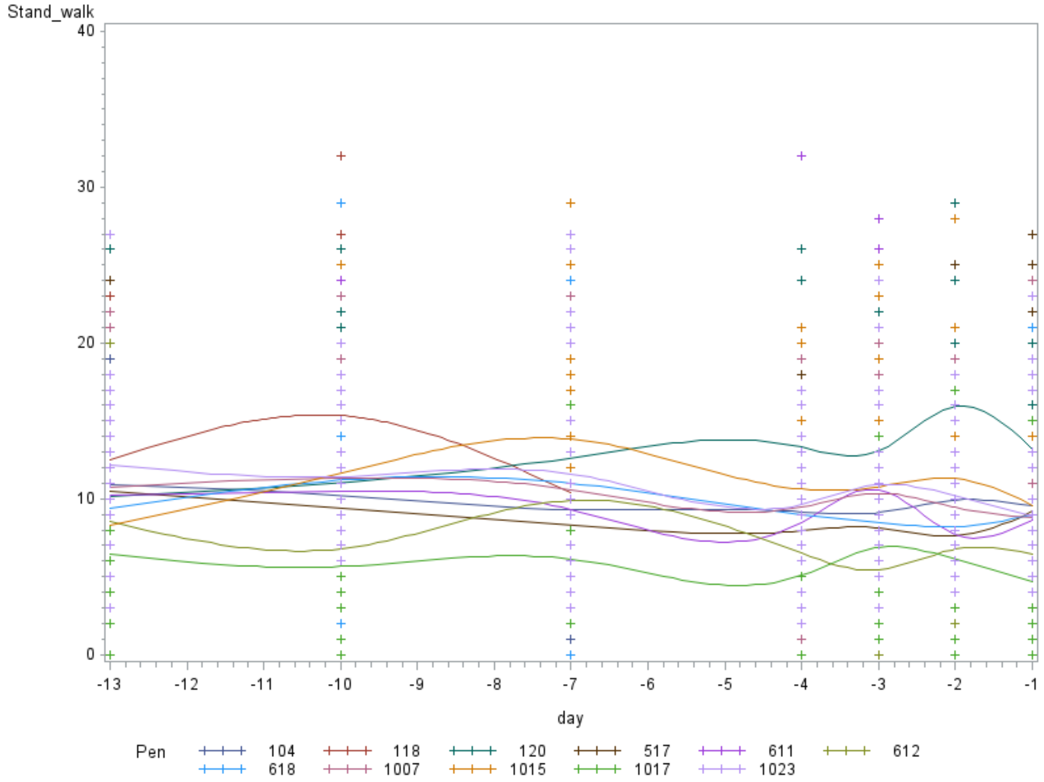

Figure A3 Standing/walking pigs on day -13, -10, -7, -4, -3, -2 and -1 before an outbreak (10 pens).

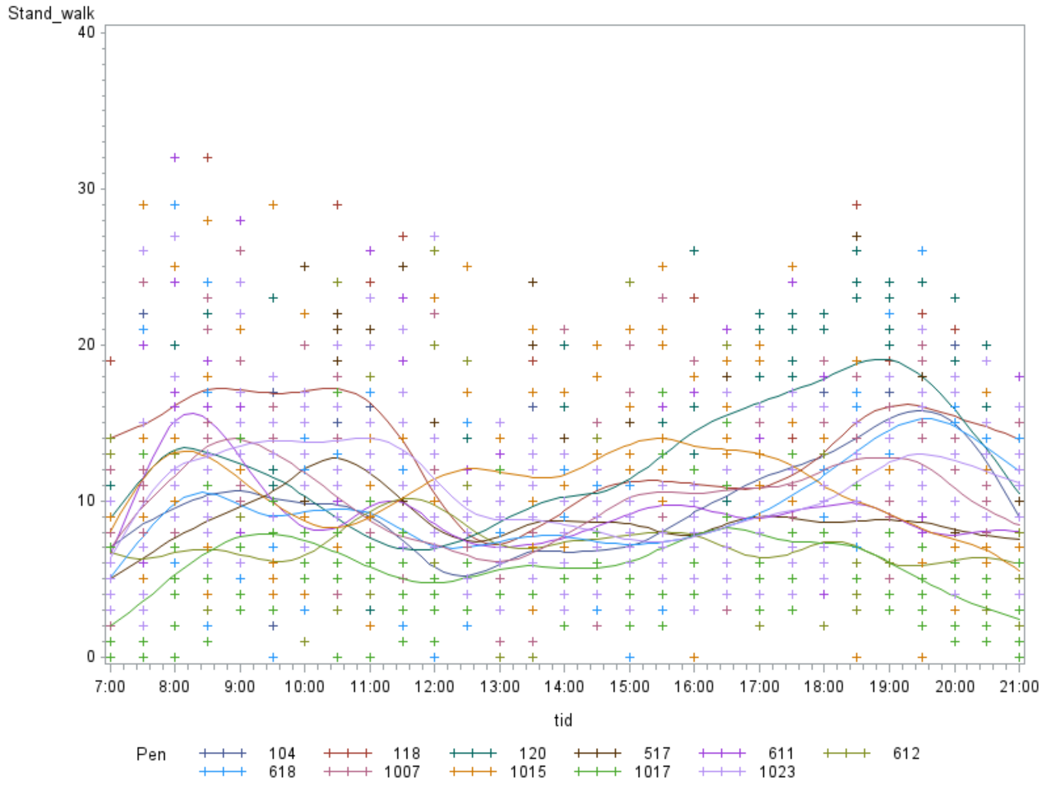

Figure A4 Standing/walking pigs from 0700-2100 h on the pilot study recording days (10 pens).